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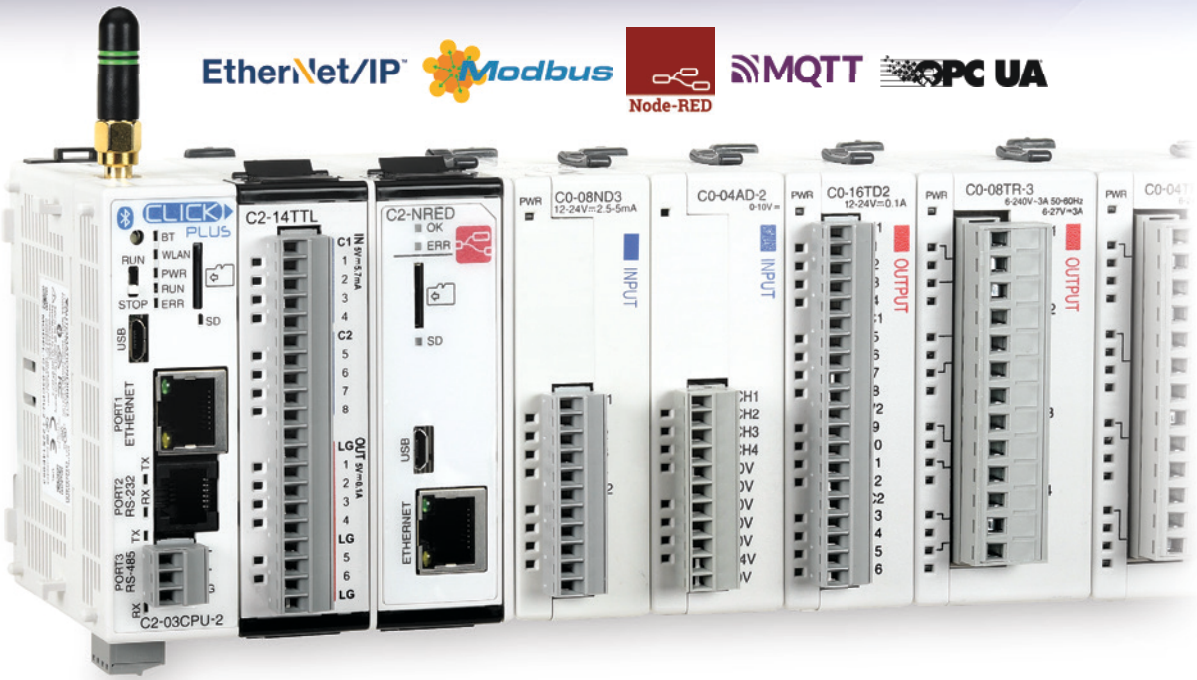

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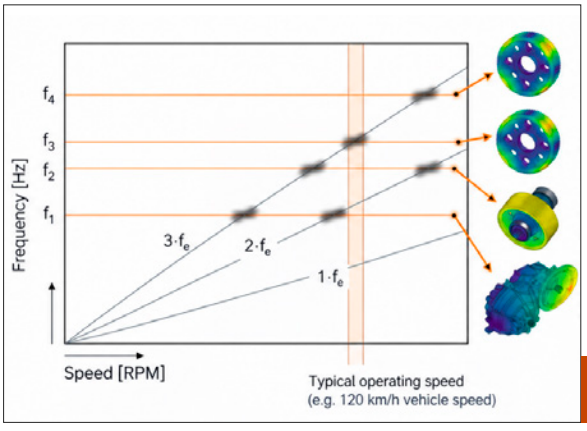

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34 Design of Low–Noise Powder-Metal Gears: From Mesh Excitation to System Response
This article presents a design methodology for gears in electric drive units in which material properties, tooth microgeometry and gear–body architecture are developed as a single NVH concept.

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BRAIN TEASER

The Quiet Fix That Isn't

A gearbox is throwing a high vibration alarm. Maintenance swaps the rigid coupling for a flexible jaw coupling. Vibration readings drop immediately, and the alarm clears.

Question:

Is the problem solved?

Join the discussion

Comment at
linkedin.com/company/power-transmission-engineering
on LinkedIn or use
#PTEBrainTeaser
to share your answer.

Selected responses may be featured in an upcoming issue.
Answer revealed in the next issue.

Last issue we asked: An engineer slows a conveyor motor from 60 Hz to 30 Hz using a VFD to save energy. The motor isn't overloaded—so why is it overheating?

Answer: The cooling fan. On a standard TEFC motor, the fan is shaft-mounted—half the speed means half the airflow, but heat from electrical losses doesn't drop proportionally. The motor slowly cooks itself. The fix is either an independently powered blower or a motor rated for inverter duty across the full speed range.

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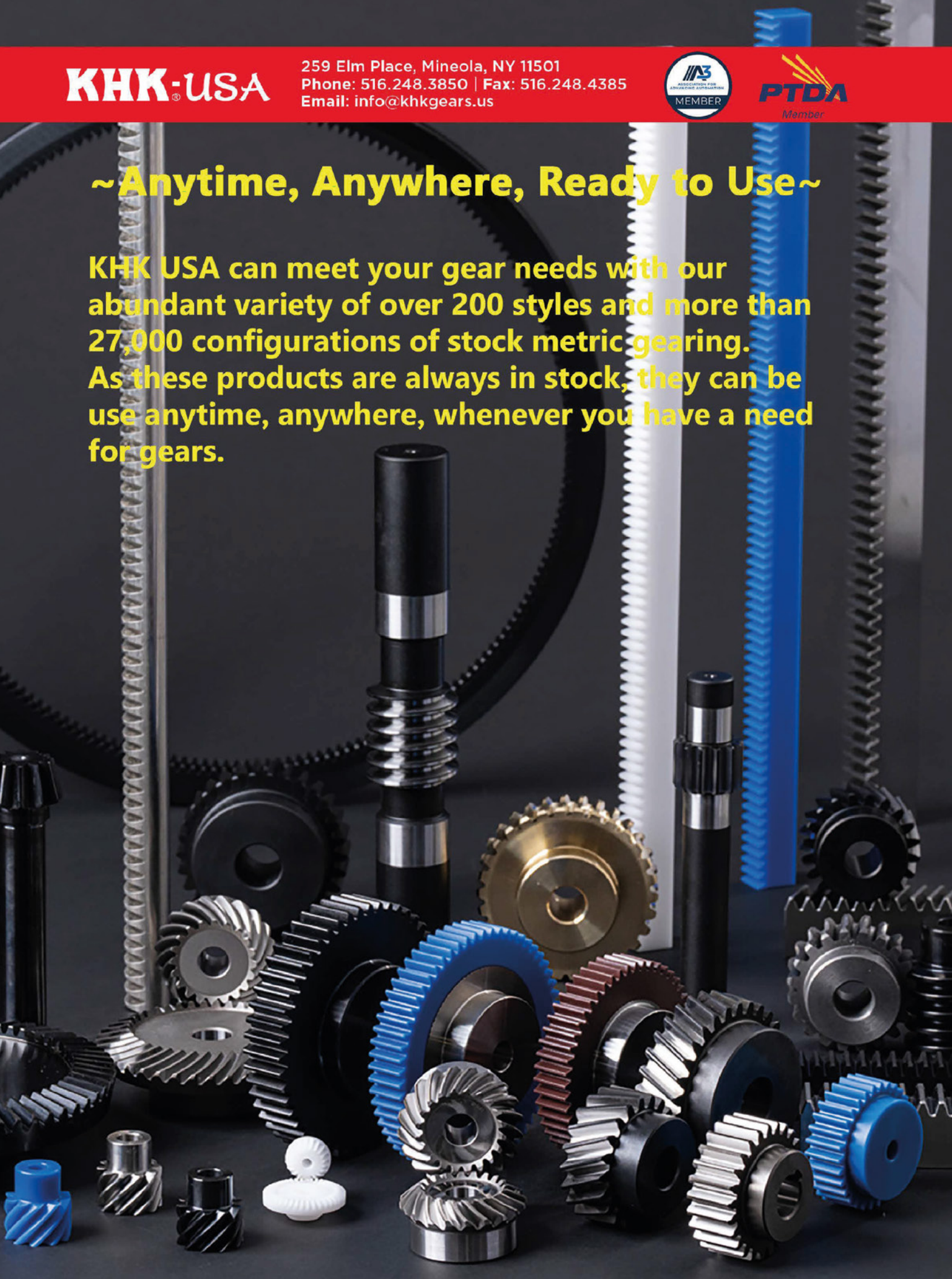

PTE VIDEOS

Growing Groves YouTube Video Series



Growing Groves is a team of career engineers and technical sales leaders who improve upon traditional recruitment methods by pre-screening candidates with industry-relevant and career-developed perspectives. Learn more here:

powertransmission.com/companies/growing-groves-llc

Agility Robotics Demo at Schaeffler Symposium



Agility Robotics Demo during Schaeffler's Automotive Symposium in Detroit. Schaeffler is deploying these humanoids across its plant network to transform manufacturing, logistics and warehouse operations.

youtube.com/shorts/H9wgi5TJyhI

PTE REVOLUTIONS

GM Moves Heavy-Duty Pickups to Rack-and-Pinion Steering



GM will equip the 2027 Chevrolet Silverado HD and GMC Sierra HD with rack-and-pinion electric power steering, replacing the hydraulic recirculating-ball gear the trucks have used until now. GM says this is a first for heavy-duty pickups.

geartechnology.com/gm-moves-heavy-duty-pickups-to-rack-and-pinion-steering

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Engineers perform routine maintenance on a robotic application.

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The Homemade Heroes of Portland

Matthew Jaster, Director, Editorial Content

Nestled in Forest Park, the Pittock Mansion is one of Portland's crowning jewels and presented an exciting challenge for Laika's artists and artisans to re-create and reimagine. **(Image: Laika Studio)**

Laika Studios, founded in 2005 as a spinoff from Will Vinton Studios, specializes in traditional handmade stop-motion animation with modern innovations like 3D printing and a priority for artistic craftsmanship over short-term profitability. Every film has been nominated for the Academy Award for Best Animated Feature including *Coraline, ParaNorman, The Box Trolls, Kubo and the Two Strings* and *Missing Link*.

Wildwood, released in October 2026, will certainly join this group when the next round of nominations is announced on January 21, 2027. Laika's longest and most ambitious project to date, *Wildwood* has a running time of 131 minutes and boasts 233 unique puppets and 117 handmade sets.

If you've watched any of these films, I hope you've stayed through the credits to watch the time-lapse footage of what it takes to film a stop-motion animated sequence. The end credits of *The Box Trolls* is a personal favorite.

What does this animated studio have to do with manufacturing you may ask? Look no further than the carefully constructed puppets themselves, featuring intricate internal skeletons built with specialized gears, rotating joints and precision-engineered gear systems for motion control.

Large props and vehicles are built using waterjet-cut aluminum bronze interiors and cast bronze hinges and are managed by their CAD, vacuum-casting and motion control teams. When a film takes 16 years to complete start to finish, it's no surprise the studio treats the day-to-day production as if they're running a highly advanced manufacturing facility.

For *Wildwood*, the studio created a new hand technology allowing knuckles to bend naturally and withstand thousands of adjustments without breaking. This was accomplished with components machined via EDM.

This "all hands-on deck approach" should inspire all engineers to step away from their computers, walk the shop floor and find a corner of the facility where they can still get their hands dirty. Laika combines CGI software with industrial manufacturing tools to enhance the human artistry element in a time when Claude wants to take credit for everything. Travis Knight said as much during a recent interview with the *New York Times* entitled, "The Director of *Wildwood* Knows AI Cannot Do What He Does."

"With AI, the entire history of the artistry and creativity that we have collectively as humanity invented is now being ingested by machines and spat back out at as if it's something that's been created. It is plagiarism. It is theft. You have to admire how extraordinarily sophisticated the technology is, but it has no soul."

Thankfully, more than 1,000 craftspeople and artists put their hearts and souls into creating Laika's latest stop-motion adventure. I'm calling them the "Homemade Heroes of Portland," fighting the good fight in the war on craftsmanship and proving Claude can't quite do everything these artists and manufacturers can.

Laika will continue to make ambitious stop-motion animated films in the future including an animated thriller called *The Night Gardener* and an adaptation of Susanna Clarke's unfilmable novel *Piranesi*.

If audiences continue to support filmmaking experiences like this, I'm confident the human element to storytelling, manufacturing and engineering can—and ultimately will—be preserved.

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ZERO-MAX
Introduces New IP68-Rated Crown Gear Drives



For 40 years, Zero-Max has introduced a new line of IP68-rated Crown Gear Drives featuring corrosion protection and food-grade lubrication while providing an enhanced level of protection against dust, dirt, debris and water infiltration. The new IP68-rated design builds on the proven Crown Gear design's 60-plus year application history, while providing upgraded ingress protection. These design enhancements open the door to applications requiring greater environmental protection, including food processing, food packaging, washdown environments and outdoor installations. The IP68 rating assures the Crown Gear Drives are dust-tight and protected against water intrusion. Crown Gear Drives with this rating provide an added level of protection for applications that experience water spray and periods of immersion.

"By upgrading the Crown Gear Drive from IP65 to IP68 protection, we've taken a proven, compact right-angle power transmission design and made it suitable for an even broader range of demanding applications," said Scott Boersma, director of sales and marketing, Zero-Max. "The combination of ingress protection, corrosion-resistant construction, food-grade lubrication, maintenance-free operation, and compact design makes the new IP68-rated Crown Gear an ideal solution for applications where environmental protection is critical."

Ideal for food processing, food packaging and other applications requiring frequent washdowns, the IP68-rated Crown Gear Drives feature a nickel-plated aluminum housing, stainless-steel shafts and purpose-built NBR-covered shaft seals designed to provide additional protection against water, washdown chemicals, process chemicals and corrosive elements.

Most importantly, the IP68-rated Crown Gear Drives feature a bright, clean, water-shedding design that minimizes bacteria traps, making them suited for applications where cleanliness and hygienic equipment design are important considerations. The fully enclosed design helps prevent contamination from water, chemicals and debris while providing protection for installations exposed to harsh operating conditions, including frequent washdowns, immersion, humidity, condensation, rain, sunlight and temperature extremes.

IP68-rated Crown Gear Drives are prelubricated at the factory and lubed for life with H1 food-grade grease for the gears and bearings, eliminating the need for routine lubrication and simplifying maintenance requirements. The Crown Gear Drives incorporate heat-treated AGMA Class 10 spiral bevel gears, precision hardened and ground ball bearings, and a sealed design for dependable and quiet transmission of rotational speed and power.

Standard operating temperatures range from -4°F to +212°F (-20°C to +100°C), with wider temperature ranges available upon request. The Crown Gear Drives are capable of speeds up to 2,000 rpm. IP68-rated Crown Gear Drives are available in 1:1 and 2:1 ratios and in two-way, three-way and counterrotating shaft configurations. Shafts are available in diameters of 3/8, 1/2, 5/8, 3/4 and 1 inch. The low-backlash Crown Gear design provides an efficient and compact means of transferring rotational speed and power while maintaining quiet operation. The Crown Gear Drives are available in multiple sizes and models to accommodate a broad range of horsepower, torque and shaft-speed requirements.

Zero-Max Crown Gear Drives are used in applications ranging from agricultural equipment and food processing systems to specialized equipment such as a vertical-opening glass wall systems aboard cruise ships, where smooth, quiet and dependable operation is a must. Customization is also available to meet the needs of specific applications. Different shaft lengths, drilled-and-tapped shaft-ends, external threads, keyless shafts, limited housing modifications, and changes in platings/coatings are some examples that can be easily accommodated. Contact the Zero-Max factory to discuss customization options if needed for an application.

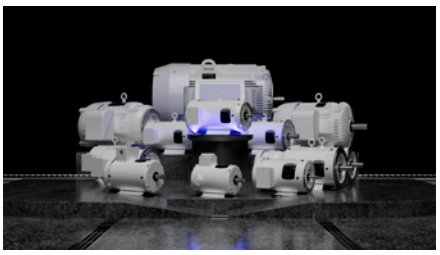
The new IP68-rated Crown Gear Drives have been tested by an independent laboratory for ingress protection. The upgraded sealing system incorporates the field-proven features of the previous IP65-rated design while providing the added protection required for the higher IP68 rating. As a result, the new IP68-rated Crown Gear Drives are completely interchangeable for

all applications previously using IP65-rated Crown Gear Drives from Zero-Max. This provides customers with an upgraded level of environmental protection without any change in size, appearance or price.

zero-max.com

ABB BALDOR–RELIANCE

Marks Four Decades of Washdown Motors



For 40 years, the ABB Baldor-Reliance washdown motor line has delivered the durability food processors need in harsh washdown environments. This year, ABB marks four decades of the motor line by expanding the portfolio to include White Washdown models up to 150 horsepower with NEMA Premium 4 efficiency, pairing proven durability with the power and efficiency today's processing operations demand.

The ABB Baldor-Reliance White Washdown motor was introduced in 1986 to address the damaging effects of moisture and constant cleaning on electric motors, setting an industry standard for motor performance in demanding washdown environments. A team of engineers examined the most common failure modes, including corrosion on external and internal motor components, winding failures caused by water ingress and bearing failures from grease contamination. Their solutions became the foundation of a product line that continues to evolve four decades later. Since then, ABB has continued to advance the platform with motor technology that helps processors extend equipment life, maximize uptime and maintain efficient production.

"For 40 years, food processors have relied on ABB's washdown motors to keep production running safely and efficiently," said Brandon Canclini, global product manager for ABB definite purpose motors. "What started as a solution for keeping motors running in wet and humid conditions has evolved to help customers protect the food supply from bacteria and other contamination while delivering the energy savings operators expect today."

Durability begins with multiple layers of protection. ABB coats White Washdown motors with a white two-part epoxy finish that is five times more resistant to chipping than a standard paint system, and applies an epoxy primer to the rotor for internal corrosion protection. Neoprene rubber gaskets replace traditional paper or cork gaskets to create a tight, waterproof seal at the conduit box and frame junction. A contact lip seal and v-ring slinger work together at the shaft end to prevent water from entering the motor, while double-sealed bearings guard against grease contamination and extend bearing life in wet environments. A precision-balanced, epoxy-coated rotor, 300-series stainless steel shaft and hardware provide additional protection, and removable condensation drains help manage moisture.

As the food and beverage industry evolved over the past 40 years and sanitation requirements grew more stringent, ABB expanded its washdown motor line to meet the changing needs of food processing operations. The portfolio now spans motors designed for environments ranging from light washdown duty to IP69-rated high-pressure, high-temperature cleaning applications.

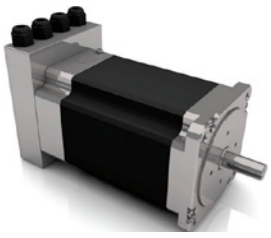
ABB's complete washdown portfolio consists of cast iron, rolled steel and stainless steel motors, supporting close-coupled pumps, jet pumps,



feather pickers, cut saws and brakes, with inverter duty and vector duty options available. And now, the expanded portfolio gives processors higher-horsepower solutions without sacrificing the durability required for wet and humid environments.

abb.com

BISON
Expands Global Access to Stepper Motors



Bison now brings MAE stepper motors to customers worldwide, expanding access to proven motion-control solutions for OEMs and equipment designers.

Combining precise positioning, high torque and flexible configuration options, MAE stepper motors help engineers achieve accurate, repeatable motion across a wide range of industrial and commercial applications.

"Engineers are often balancing precision, performance, and integration requirements," said Matt Fuss, business unit manager, Bison. "MAE stepper motors are designed to address those challenges with accurate positioning, high torque and a broad range of configuration options that simplify machine design."

The two-phase hybrid stepper motors feature a 1.8-degree step angle and support micro-stepping up to 204,800 steps per revolution, enabling smooth operation and fine positioning control. Available in NEMA 17, 23 and 34 frame sizes, the motors accommodate a variety of design requirements and deliver holding torques up to 12 Nm.

Designed to support both open-loop and closed-loop motion-control systems, MAE stepper motors can be configured with planetary gearboxes, high resolution encoders—incremental or absolute, brakes and integrated electronics to meet specific application requirements. A range of built-in controller options are also available, from economical Step & Direction and RS485 solutions to advanced closed-loop controllers featuring industrial communication bus connection via EtherCAT, CANopen or Modbus.

One motor platform, countless configurations: the MAE stepper motor range stands out for its high modularity, enabling the flexible integration of planetary gearboxes, high resolution encoders, brakes and integrated electronics to create the optimal solution for any application.

Additional customization options, including modified shafts, cables, connectors and enhanced IP protection, allow engineers to optimize performance for challenging operating environments while simplifying machine integration. Regional configurations and certification options are available.

MAE stepper motors are suited for a broad range of applications, including industrial automation systems, intralogistics AGV/LGV/AMR, packaging equipment, medical and laboratory devices, farm automation and agriculture, flexographic machines, CNC machinery and robotics. Available harsh-environment packaging options support reliable operation in demanding applications exposed to dust, moisture and vibration.

Now available through Bison's global sales, engineering, and support organization, MAE stepper motors provide customers with easier access to configurable motion-control solutions backed by application expertise and responsive technical support.

bisonametek.com

MAYR POWER TRANSMISSION
Highlights Customized Solutions at SPS 2026

At the SPS 2026 in Nuremberg, Mayr Power Transmission presented highly integrated solutions



that create space for smooth processes. Safety brakes such as the ROBA topstop series are used for this purpose. The matching ROBA brake-checker module enables sensorless brake monitoring. Combined with the ROBA gateway, the system delivers valuable data for proactive machine maintenance, a digital twin and smart production environments.

At the round table, the drive specialist from the Allgäu region also presented hollow shaft brakes for applications with high torque and a large space requirement inside the application. In automated production systems, on robots or on gravity-loaded axes, the protection of people and material is essential; uncompromising safety must not be up for discussion. Safety brakes built according to the fail-safe principle—i.e., applied in de-energized condition—provide the foundation here. The ROBA topstop holds the loads in position reliably and prevents uncontrolled movements in case of power outages or emergency stops. As they are placed between the motor and the output, the brakes can be retrofitted in existing constructions—a solution that reduces effort and costs. For everyday industrial use, the ROBA topstop brake system is designed as an independent, compact module. O-rings at the interfaces ensure reliable sealing against dust and moisture—the brakes achieve IP66 protection as standard. The vertical axes remain secured even when



the drive is dismantled, which is advantageous during maintenance and transport. Thanks to the adaptable flange dimensions, the system can be easily integrated into existing constructions.

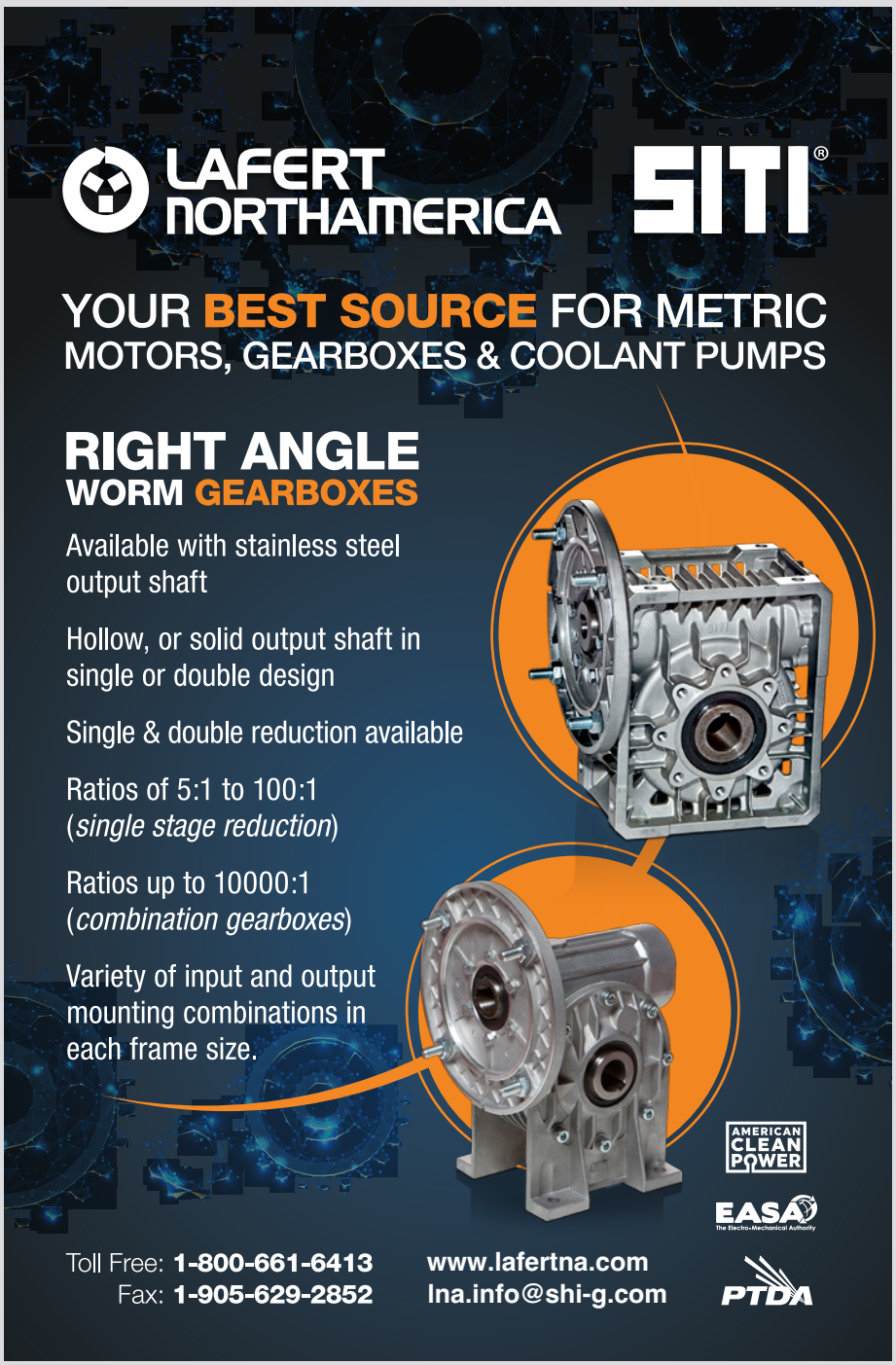
Brakes from the modular ROBA servostop series are suitable for a wide variety of installation situations. There is a choice of servo brakes for standard servomotors with hub and toothed rotor, in a classic or slim design. The ROBA servostop cobot is the ideal solution for integration into the joints of lightweight robots.

With their extremely slim design and low weight, ROBA servostop safety brakes are tailored to the requirements of robotics and easily withstand demanding operating conditions. After the power is switched off or in case of power failure, the brakes ensure reliable and secure holding of the axes in any position.

Torque motors with a large, free inner diameter are used in applications with high torques. Rotational freedom and unobstructed installation space on the inside are decisive factors here. From robotics through observation technology to maritime systems and deep-sea robotics: Such high-performance direct drives solve several design problems and, thanks to their annular construction, are what make certain designs possible in the first place. One challenge is finding safety brakes that fit the same annular geometry. Mayr Power Transmission develops electromagnetic hollow shaft brakes as customer-specific solutions for precisely this requirement.

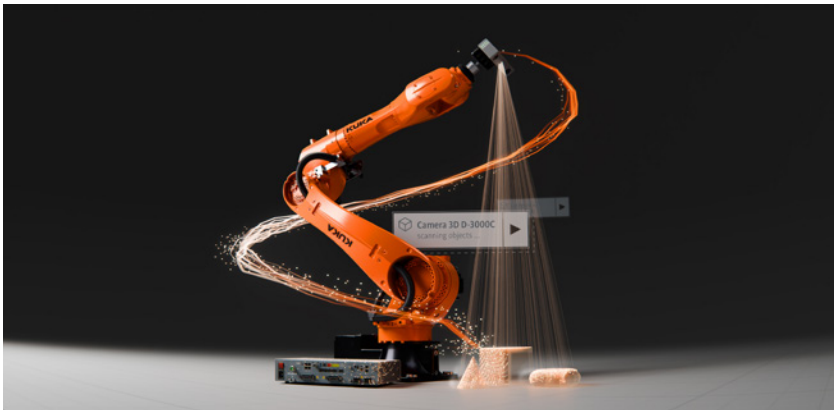
With the ROBA brake-checker, Mayr offers a module that monitors the safety brakes without the need for additional sensors. It recognizes the brake's condition based on current and voltage trends, enabling proactive maintenance. Critical parameters—such as switching time, coil temperature and functional reserves—are reliably detected. The additional ROBA gateway module renders the solution networkcompatible so that the collected data can be integrated into existing remote maintenance systems or digital twins can be created, for example, thus ensuring smart production and more transparency in the drive line. SPS 2026 took place in Nuremberg in November.

mayr.com



KUKA ROBOTICS

Simplifies Industrial Image Processing With AI-Powered Vision Software



Kuka Robotics has released its new *iiQKA.AI Vision*, an AI-powered software designed to fully integrate into the Kuka ecosystem for simple, fast commissioning. The solution is particularly valuable for integrators and users with limited vision experience who want to efficiently integrate industrial vision into their automation solutions, without complex additional systems or high upfront costs.

The intelligent software supports both 2D and 3D vision and enables typical applications such as bin picking, assembly, quality control and depalletizing. With intuitive drag-and-drop configuration, users can quickly implement productive vision applications without specialized knowledge.

For low-latency AI inference and secure, local data processing, the Kuka *iiQKA.AI Vision's* image processing runs as edge computing directly in the controller on the Kuka *AI Extension Platform*, an integrated computing unit based on the NVIDIA Jetson Orin module. The system's sufficient computing power supports demanding vision AI tasks without the added complexity that often comes with industrial image processing. No cloud connection, other external systems or additional infrastructure is required.

All data processing takes place locally within the system and images are processed and stored onboard. As a result, users benefit from high data security and independence from network connections. This not only reduces integration effort but also can help lower the total cost of ownership (TCO) over time and simplify the system architecture. Cameras and other compatible components are available directly from Kuka and are tailored to typical industrial requirements.

To support end-to-end workflow, the application is configured entirely in Kuka's *iiQWorks* system via a standalone vision application with a graphical user interface. Drag-and-drop functionality, pre-built templates for typical applications and guided workflows support users from setup through commissioning, helping them implement vision applications efficiently. Robust image processing ensures process reliability with precise 2D and 3D object recognition, automatic orientation detection, and gripper point calculation. It works reliably even with varying components and changing lighting conditions. Seamless integration with *iiQWorks* and the robot controller creates a unified system from engineering through operation, offering a consistent workflow from configuration to deployment as well as centralized management and monitoring via the web interface.

For object recognition in robust processes, the AI algorithms used in *iiQKA.AI Vision* precisely distinguish objects from the background and automatically calculate suitable gripper points. Precise positioning and gripper information are calculated based on image data or point clouds and transmitted directly to the robot, resulting in seamless, stable processes from detection to execution and consistently high image quality.

With *iiQKA.AI Vision*, Kuka offers an efficient, ready-to-use image processing solution that significantly simplifies the transition to industrial vision applications and increases productivity.

kuka.com

IGUS

Launches New DeviceNet Cable Designed for Dynamic Robotic Applications

Igus has expanded its CFROBOT8.PLUS robot cable family with a new DeviceNet cable designed to handle up to ±360 degrees per meter of torsion in dynamic robotic applications. The CFROBOT8.PLUS family is engineered for up to 10 million torsional cycles, with a specialized shield design that provides flexibility during continuous robotic movement. The cables also feature a reduced outer diameter—up to 21 percent smaller than previous CFROBOT8 models—making them a good fit for tight spaces.

A tinned-copper braided shield helps maintain signal integrity under demanding conditions, while oil and UV resistance enables reliable use in both indoor and outdoor environments.

Igus' new DeviceNet cable is suited to a wide range of applications including six-axis robots, handling systems, machine tools, linear and lead screw systems and other applications with continuous torsional movement.

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Beyond the Breakdown

How a World War II solution continues to shape maintenance strategies today

Matthew Jaster, Director, Editorial Content



Maintenance strategies created by the RAF during World War II are still relevant in 2026.

Tom Knauer, business strategy manager at Balluff Inc., took a deep dive into the origins of proactive/optimized maintenance practices as he became more involved in Balluff's condition monitoring program. While the industry typically focused on recent practices, and optimized maintenance strategies, Knauer came across Stephen Budiansky's *Blackett's War,* a history of Great Britain's World War II effort to counter U-boat attacks by applying math, analytics and probability theory. This research became a blueprint for the data-driven maintenance approach needed on the modern shop floor.

"One topic of interest was the analysis and improvement of maintenance processes to increase Royal Air Force (RAF) aircraft availability/OEE, which has a direct connection to today's maintenance practice goals," Knauer said. "The concept was that in certain cases less maintenance is better. Maintaining items that do not or rarely fail wastes time, people and parts; and occasionally (when done incorrectly) maintenance can lead to more, rather than fewer, failures."

The RAF learned that it may be best to apply different maintenance approaches to different components of an asset. Some parts may be served with a "run to fail" approach, some by preventative maintenance or a proactive approach—the data and a "criticality analysis" can help figure out the best approach for each component on a case-by-case basis.

The success of condition monitoring and predictive maintenance technology in the future—AI agents, smart automation, hybrid models and smart sensors—will greatly depend on the quality and availability of data, workforce trust in AI-generated recommendations and solving potential cybersecurity concerns. Yet lessons the RAF learned during World War II still shape the evolution of sensor technology and condition monitoring tools 84 years later.

Lessons Learned in World War II

According to Britain's Air Ministry, the RAF flew thousands of anti-submarine and maritime reconnaissance sorties against German U-boats. When Churchill questioned aircraft serviceability rates in the early 1940s, Coastal Command investigated why available planes were flying so few sorties. The cause was maintenance—not pilot endurance or sortie restrictions.

The key insight was that the RAF was measuring the wrong thing. Commanders were judged on serviceability, meaning the share of aircraft ready to fly at any moment. That rewarded keeping planes on the ground in reserve rather than flying them. Analysts proposed linking maintenance schedules directly to the number of sorties the planes were expected to fly and ordering squadrons to ignore the serviceability target rate.

The trials showed something counterintuitive: while serviceability rates dropped, monthly flying hours went up. Planes spent less time idle, so fewer were sitting ready at any moment, but far more patrol work was done.

The method was to treat maintenance like a factory production line, matching servicing capacity to a planned flying program instead of reacting to whatever came in. Flying hours increased, airfield capacity grew and the RAF achieved large manpower savings without reducing total effort. Coastal Command aircraft received periodic "minor" and "major" inspections based on flying hours.

In other words, the maintenance service itself was introducing faults through disturbed components, reassembly errors and early failures of new parts. This finding challenged the assumption that more frequent maintenance is always safer. Decades later, the same idea became a pillar of reliability-centered maintenance used in the 1970s for airlines.

During Knauer's presentation on the subject at Automate 2026 in Chicago, he examined which parts of the RAF's maintenance process are applicable today. This included using actual production data to address bottlenecks, optimizing personnel/resource scheduling, analyzing failure data to implement condition monitoring/predictive maintenance and applying longer maintenance intervals when justified by the data.

The Condition Monitoring Playbook Today

The approach Balluff takes with customers today starts with an assessment of the most critical assets in the plant. "How often could a failure potentially occur? What's the cost to fix that failure in terms of people's time, in terms of the components? What's the cost of lost production? We're then carefully going over the data to find the best possible solution for the customer," Knauer said.

The main challenge in MRO today is that each application and manufacturer has a different risk profile in terms of costs, safety and frequency. Components featured regularly in this magazine, including motors, pumps, fans, conveyor drives and gearboxes, benefit from a maintenance strategy that includes a variety of sensor technologies. However, every application and industry is different and brings their own unique challenges to production.

In a perfect world, condition monitoring and predictive maintenance would prevent every failure and catastrophe from ever taking place. More times than not, it is the breakdown of a part that gives the educational insight the company needs moving forward.

"Unfortunately, in our business, we occasionally provide the best solution for a component that has already failed. We had one case study at an automotive manufacturing facility, for example, where the motor and gearbox went down and not only destroyed the conveyor line but the materials on it," Knauer said. "By studying the failure, we were able to provide a comprehensive maintenance plan to prevent future shutdowns."

For a different application, Balluff was asked to provide a system to map the complex processes in a woodworking machine, suitable for both stationary integration and mobile applications. Balluff offered the BCM condition monitoring sensor in combination with the CMTK condition monitoring toolkit to solve the diverse requirements. This system enabled simple monitoring and visualization of vibration, temperature and other environmental conditions.

"The consensus seems to be that while temperature and vibration can be very simple and easy to apply on a variety of applications—especially for motion applications—these sensors shouldn't be the only technologies to consider," Knauer said. "Bearing technology, for example, might include accelerometers to capture high-frequency resonances or acoustic emission and ultrasonic sensors to pick up stress waves from metal-to-metal contact."

Today, monitoring is also moving toward bearings with integrated sensing built into the unit itself, sending the necessary data to a laptop, smartphone or tablet.

Depending on the course of action, a manufacturer might need to weigh the cost benefits between purchasing new equipment altogether or retrofitting older machines to provide the necessary maintenance strategies that work best.

Retrofitting offers a wide range of options, including condition monitoring as a service. Service providers supply sensors, help customers figure out where to install them, integrate hardware and software and provide ongoing support. Balluff and other traditional sensor suppliers offer customers greater ownership of the sensor technology with this method.

"The customer owns the data; they own the hardware and could potentially even write code. Then they can take that data and do whatever they want with it. They can take it up into the cloud or take it up to their CMMS system. There's flexibility there and room to build out other systems," Knauer added. "For example, you may already be checking the speed of a motor or the power of a motor, right? That may already be a capability you have on your drive or motor system and that data can provide basic information for a condition-based or predictive system."

Motor with sensor **(Image: Balluff)**



The Next Strategic Step

Prescriptive maintenance predicts when equipment is likely to fail and recommends specific actions that will prevent or reduce this failure.

"Prescriptive maintenance is adding features and capabilities to your condition-based or predictive system and builds an additional layer on top of the more proactive approaches," Knauer said. "You have the necessary information built up in a database as well as the steps needed to solve the issue, and you can present this to the maintenance team or write a work order."

Knauer pointed to a familiar scene: a 30-year manufacturing veteran walks by a machine and stops at once because something doesn't sound right. "They know exactly what needs to be done to fix it just because it sounds different. This invaluable knowledge is disappearing. We have a new generation coming up with a separate set of technological tools. How can we as suppliers and manufacturers provide tools that can be as valuable to this generation as the machinist on the shop floor for 30-plus years that knows by sound alone when equipment is failing?"

Traditionally, Knauer said, manufacturers and end users have been the most interested in condition monitoring and predictive maintenance strategies. But he sees a future where OEMs build much larger condition-based monitoring, predictive and prescriptive maintenance programs.

"This is a value-added service that many of these OEMs are not taking advantage of today, so I could see a subscription-based maintenance package where companies have the flexibility and technology to stay ahead of component failures or unplanned downtime."

Knauer spoke with an Italian OEM that builds large CNC machines for aerospace customers in Asia. Its biggest bottleneck was the cost of sending MRO teams to remote sites to fix the equipment. If all the data were available at once, the company might not need to send a crew all the way from Italy to do the work.

"Maybe they can hire somebody on site to look over the data and work with the maintenance team remotely," Knauer said. "Or if they have no choice but to send maintenance personnel, at least they have a better idea of what's going wrong with the machine and what spare parts and tools they'll need to complete the work. Anyone involved in repair knows some of the work is standing around and waiting for the parts and tools to arrive."

Where AI Fits In

Artificial intelligence is poised to accelerate every step of MRO. Condition monitoring generates more data than most maintenance teams can review, everything from temperature, vibration and motor currents to runtime counts around the clock. Machine learning models can quickly determine what "running normal" looks like for

Gearbox with dedicated sensor for maintenance **(Image: Balluff)**



gearboxes, motors and bearings and provide the information when something goes wrong long before a field technician might notice the problem.

Then there's the generative AI piece of the puzzle. A field technician can simply ask AI why a pump keeps tripping and receive an answer built on the machine's own historic data. Instead of digging through records and work orders, the tech has the information immediately and the steps and parts needed for the job. Knauer sees a future where the knowledge that once lived with the 30-year maintenance worker can be captured via sensor data and made available to whomever is on the shop floor when a failure occurs.

The RAF's lessons apply here, too. An AI system that flags every minor anomaly can recreate the over-maintenance problem Coastal Command uncovered during the war, sending crews to service equipment that was running fine and introducing new faults in the process. Much of AI's value lies in helping teams decide where not to intervene, and that depends on the same foundations mentioned at the outset: clean, consistent data, a clear ranking of which assets are most critical, secure connections between the plant floor and the cloud, and maintenance staff who trust the recommendations enough to act on them.

Despite apprehension and doubt about the use of AI in manufacturing, Knauer said MRO is an area where AI can easily exceed the hype.

"Middle school, high school and college kids today will gladly accept any tool or resource that is going to make their day-to-day job easier, right? This is what they've grown up with. They have an extremely high comfort level with accepting AI-based prescriptive maintenance tools. It feels very much like it's going to be a career enhancer rather than a career destroyer for the next generation of manufacturers and maintenance personnel."

AI can sharpen a maintenance strategy, but it can't replace one. The plants likely to see the biggest return are those that have already done the groundwork. Balluff walks customers through identifying critical assets, putting the right sensors in the right places and building a reliable data stream before asking an algorithm to make sense of it. The first step in this process is the most valuable for future success.

Knauer said the key is to start small and scale up. Take the time to perform a criticality analysis of all your equipment. What assets are most important for your operation today? You should address these challenges before continuing your condition monitoring and predictive maintenance journey. Knauer credits its former Balluff employee Will Healy with a perfect quote on the subject:

"You can either plan the downtime on your machine by using a proactive maintenance approach or your machine is going to plan it for you."

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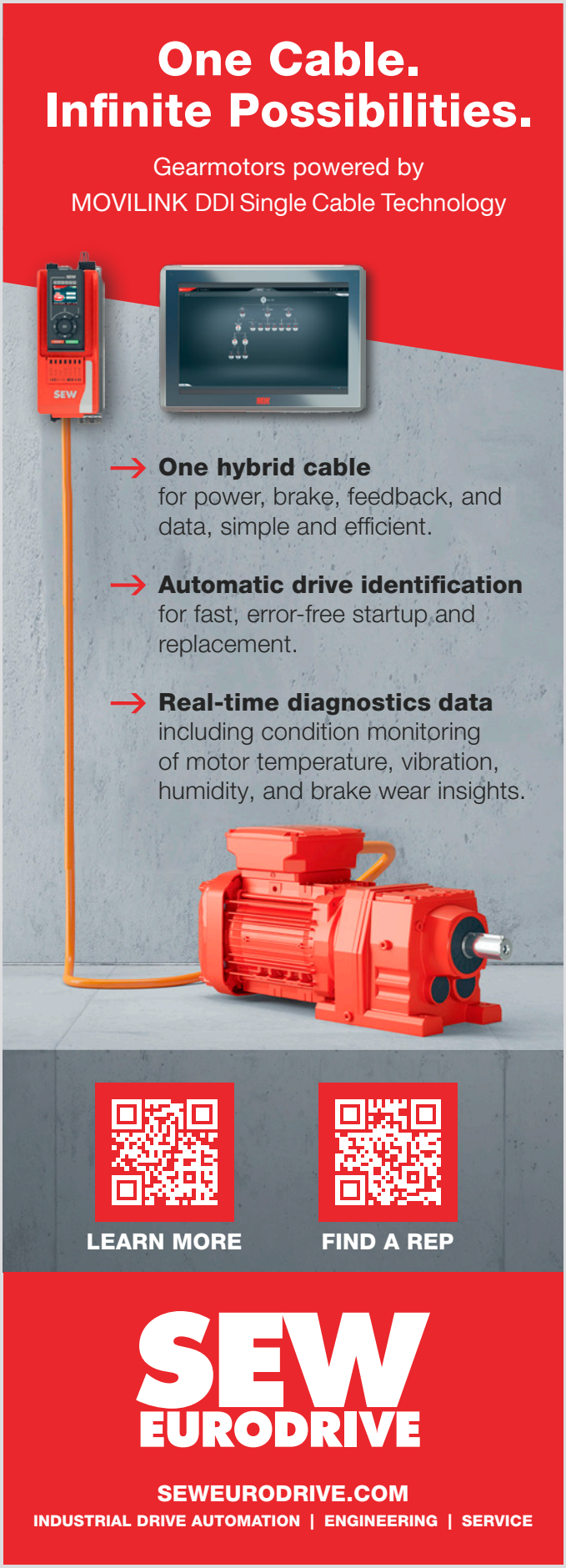



Solving High Risk Mining MRO Challenges

John Crane retrofit helps copper mine save around 288,000 liters of sealing water per day on critical tailings pump

Matthew Jaster, Director, Editorial Content

John Crane took its sealing knowledge from general industry and oil and gas and applied this expertise to the mining industry.

John Crane, a business unit of Smiths Group plc, has retrofitted a mechanical seal on a large underflow thickener slurry pump at a major copper mining operation, cutting the clean water needed for sealing by around 288,000 liters per day and supporting a move away from frequent, high-risk maintenance interventions on a production-critical asset. With a shaft diameter of approximately 270 mm, the installation represents the largest slurry seal sold by John Crane to date.

"Underflow thickener pumps are among the most critical assets in a mine's tailings circuit, so customers are understandably cautious about change," said Warren Smith, global mining market director, John Crane. "This project is a practical example of how improved sealing can reduce maintenance exposure and cut the clean water required for sealing, while supporting more predictable planned maintenance."

Mining Pump Maintenance

Smith has been involved in the mining industry for 26-plus years in a variety of positions including product development, sales, and even working on pumps in the field. He has been involved in fluid dynamics and sealing in mining as well as general industrial applications.



Regarding slurry pump maintenance, Smith said the stuffing box is the chamber through which the rotating shaft passes and which the packing is installed. The packing is designed to control leakage around the shaft, while clean gland water helps cool and lubricate the packing and limit the entry of abrasive slurry. Correct selection, installation and adjustment of the packing are important to keep pumps running longer and more efficiently.

Underflow thickener pumps are a key link in tailings handling, moving high-density slurry from the thickener into the tailings transport system. In this application, the Warman 550 pump operates at approximately 65 percent solids, where reliability is essential and any unplanned interruption can have an immediate impact on production.

Sealing components in slurry pumps can be exposed to significant wear. Abrasive particles can accelerate wear in packing arrangements and, if allowed to enter the seal chamber, can affect mechanical seal performance.

"The lifespan of packing and other wear components in slurry pumps can vary from days to weeks to months," Smith said. "It all depends on the quality of the materials selected and how their maintenance practices are implemented. Ideally, you want to keep the pump running as long as possible."

Historically, packing selection can sometimes be driven by initial purchase cost or immediate availability rather than total lifecycle performance. Smith said selecting a material that is not suited to the operating conditions, combined with ineffective maintenance practices, can lead to premature failure.

Prior to the retrofit, the pump in this mining application used a traditional packed stuffing- box arrangement. In abrasive service, that approach led to accelerated wear on the shaft sleeve, with replacement required around every four months. Although the impeller and rubber liners were typically replaced annually, sleeve changeouts were major events involving a full mechanical crew working across two shifts (around 36 hours), a 100-metric-ton crane, and extended exposure to safety and downtime risk.

"This specific mine was experiencing problems with packing and ideally wanted a continuous maintenance run of one year instead of four months. The biggest driver in this shorter maintenance interval was the gland service water had not been dependable," Smith stated.

In heavy-duty centrifugal slurry pumps, fitted with packing, gland service water (or gland seal water) is a pressurized, clean fluid injected directly into the pump's stuffing box. It helps prevent abrasive slurry from entering the stuffing box area while colling and lubricating the packing and shaft sleeve.

From a maintenance point of view, Smith said gland packing can require intervention on a daily, sometimes weekly basis just to adjust the gland and keep gland leakage at a manageable rate. The end goal is to eliminate the safety risks involved in making frequent gland adjustments.

"By designing a mechanical seal package, you're also going to reduce both water consumption and support more predictable maintenance over the long term," Smith added.

Reliability at a Premium

John Crane designed a mechanical seal package at the rear of the pump, replacing the original stuffing box (packing) arrangement and enabling a retrofit without modifications to the pump. The scope also included an adapter sleeve to suit the shaft. To support performance in mining service, the seal uses a controlled seal-flush arrangement to maintain a clean fluid environment at the seal faces and is specified with diamond-faced materials for robustness in the event seal-flush pressure drops and solids enter the seal chamber.

With this simple upgrade, John Crane was able to give the customer a mechanical seal using John Crane Diamond face technology allowing the company to regulate the gland service water. Actual operating flow is approximately 7.5–8 cubic meters per hour, compared with around 20 cubic meters per hour on a parallel pump operating with packing.

"Internally, we were now able to build the seal for whatever Warman pump ranges we had not built one for. These seals are built and designed specifically for mining applications and extend the life of rotating equipment. Our standard Type 5860 slurry seal platform was enhanced simply by adding diamond face technology. We have provided similar seals in other mining operations where we regulate the gland service water or even eliminate the water entirely," Smith said.



John Crane offers seals built specifically for mining applications that extend the life of rotating equipment.

John Crane designs its seal packages around widely used slurry pump platforms, according to Smith. This gives the organization a leg up on the competition as the engineers involved know the platform very well and understand how the pumps respond to field operations. Every new case study provides an opportunity to discover ways to enhance the product portfolio and develop better sealing solutions in the future. "We'll design our own options and use different materials to enhance longevity and increase safety throughout each application," he added.

While this application boasted the largest slurry seal John Crane has sold to date, Smith said there will be designs for even larger seals in the future. The company is working on additional applications where the seal is about as large or slightly larger than the one utilized in this copper mine application. The real work is subjecting these seals to rigorous testing prior to installation. "We're not putting anything in the field that doesn't meet the requirements of our customers as well as meeting our own expectations," he added.

Retrofit Rewards

Following installation and commissioning, the sealed pump is operating well. The seal-flush system was designed around approximately 11 cubic meters per hour at 75 psi, with actual operating flow running at approximately 7.5–8 cubic meters per hour. By comparison, a parallel pump operating with packing has been consuming around 20 cubic meters per hour of water. This indicates a reduction of roughly 12 cubic meters per hour, equivalent to approximately 288 cubic meters (288,000 liters) per day, subject to site operating conditions.

The retrofit is designed to align maintenance with the site's planned annual major service interval, when the impeller and liners are replaced, reducing the need for additional intrusive interventions during the year.

"John Crane broke into the mining industry with our successful product portfolio designed for general industry as well as oil and gas applications years ago," Smith said. "We took a step back and started designing products specifically for mining. Everything we have designed since has been evaluated at mines across the globe, specifically in Australia, South Africa, and Canada. These are the playgrounds are engineers play in."

John Crane is a specialist in flow control technologies and an innovator in solutions for rotating equipment in the energy and process industries. The company also provides mechanical seals, seal support systems, couplings and filtration systems, supported by advanced service solutions and digital diagnostics.

John Crane supplied highly specialized filtration sieves for the Artemis II program, specifically for the spacecraft's Propellant Management Devices (PMDs). Read about this application in the *PTE* August 2026 issue here:

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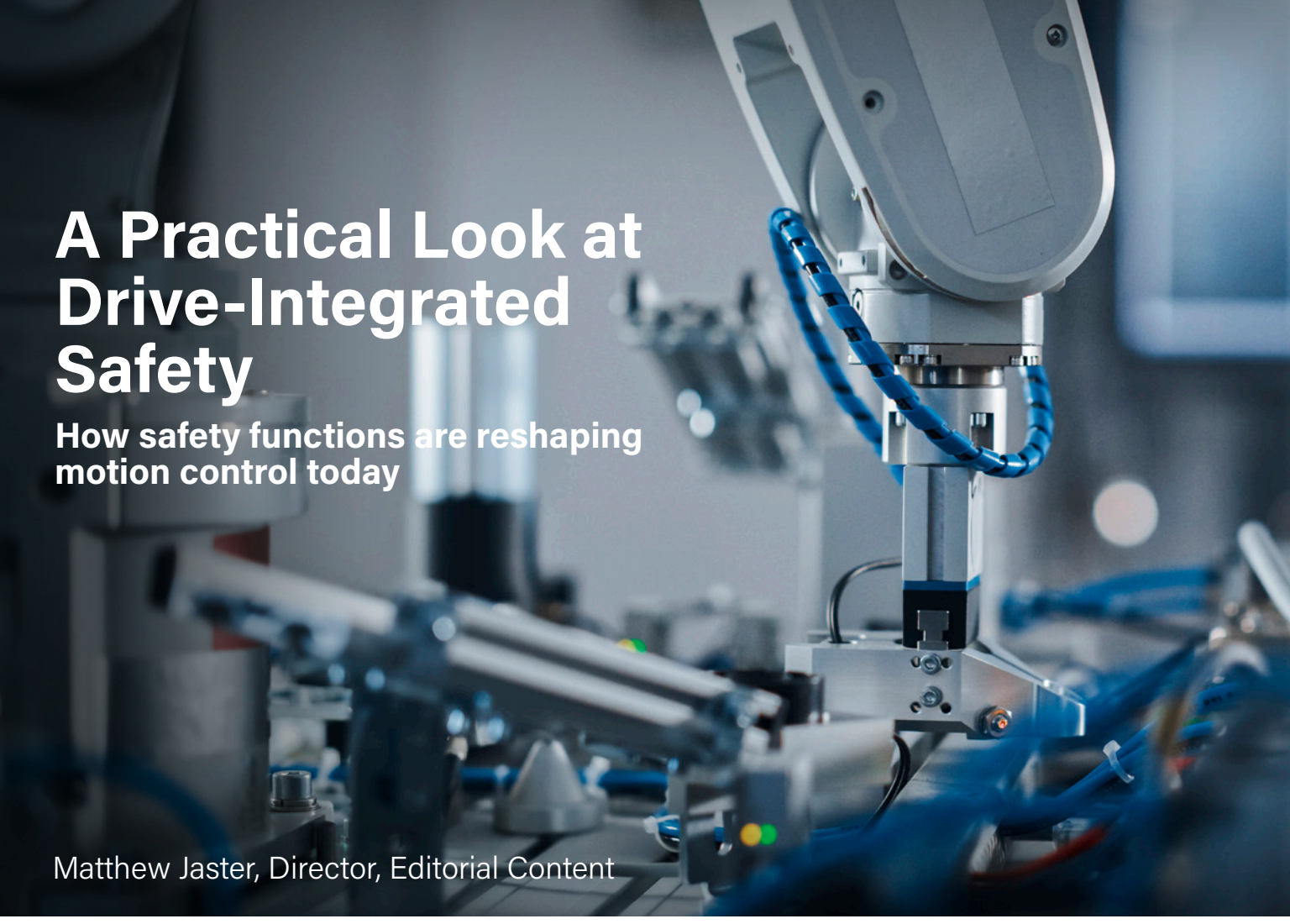
A Practical Look at Drive-Integrated Safety

How safety functions are reshaping motion control today

Matthew Jaster, Director, Editorial Content



Factory automation and manufacturing production will rely on safety standards as the industries adapt to new technologies.

The days of safety being simply an add-on to motion applications has ended. Today's machine builders need to integrate functional safety in the earliest stages of their servo-drive architecture. This helps designers simplify system architecture, reduce external safety components and cabling and build smaller more efficient machines.

With their completion of the Functional Safety certification, Elmo Motion Control now provides machine builders with advanced motion control technology that combines performance, compactness, intelligence and safety into a single platform—perfectly suited for demanding industries such as industrial automation, robotics, semiconductor manufacturing and autonomous systems. Simone Gianotti, application engineer manager at Elmo Motion Control, recently discussed the evolution of safety standards for drive technology in these applications.

For decades, safety has been extremely important in Europe, but today there is a greater emphasis on the global motion and drives market embracing tighter and more regulated safety standards. "Whenever you have a piece of equipment running by itself, whether it's a robotic arm or an autonomous vehicle, anything in the proximity of humans, safety should be one of the main drivers," Gianotti said.

Industrial robotics is at the top of that list where collaborative robots work side-by-side with human counterparts. "In those situations, it is common to have safety features implemented such as safety limited speed or safety limited torque. They make sure that when the sensor detects that the human is entering a certain area defined as potentially dangerous, the robot slows or shuts down."

Safety architecture ensures the organization is limiting the extent of what can and will go wrong. Safe Brake Control, for example, provides safe control of an external power-off brake and is used on vertical axes. If a redundant braking system fails, the drive typically invokes Safe Operating Stop where the drive holds the motor at zero speed without removing torque.

"During operation, these features help ensure the brake is working properly and allows the system to manage a fault while maintaining a predefined safety level. This becomes an even more crucial factor in applications like AGVs and AMRs where these machines are working in dynamic operating environments and require standards that partially overlap," Gianotti said.

Looking specifically at humanoid robots, Gianotti said one of the most critical safety concerns involves the robot potentially losing balance or a leg losing



power for whatever reason. So now you have an unstable system where a robot could topple on top of a human causing injury.

Gianotti said there is an international standard for this hitting the market some time in 2027. ISO/CD 25785-1 states the safety requirements for industrial mobile robots with actively controlled stability and their systems, which include robots that have an unspecified number of legs, wheels or other types of mobility.

The devil—will certainly—be in the details of the standard.

"It covers much of the information already available in safety for robotic and motion control technologies but brings new needs and objectives based on the development of robotic technology available today," Gianotti said.

Mix and Match Safety Configurations

The role a feedback device plays in safe motion today depends on the drive manufacturer.

Gianotti said there are companies in the market that developed intrinsically safe feedback. They created the feedback in such a way that they can bring that feedback to a third-party company like, for example, TÜV, and get TÜV to say, "This feedback is certified safe up to C3 PL e, a highly reliable safety classification for machine control systems."



Elmo Motion Control announced the completion of Functional Safety certification for its Titanium line of servo drives, marking a significant milestone in the company's next-generation motion control technology. **(Image: Elmo Motion Control)**

Many manufacturers—including Elmo Motion Control—are taking different feedback configurations and bringing those safety configurations to TÜV and getting them certified.

"For example, if you're looking again at our drives, you can use a functional safety feature like safety limited speed using a safe beast encoder, but maybe you can reach the same result using a dual standard B-type encoder, or maybe a B-type encoder plus a standard SinCos encoder, or an optical incremental encoder and another absolute encoder. So, there are different combinations of standard feedbacks that can still guarantee you reach the desired level of safety," Gianotti said.

The challenge remains that the drive manufacturer needs to take that configuration and prove that they have all the diagnostic coverage and redundancy to reach that level, even if you are using standard devices instead of safety-certified ones.

So how are safety protocols changing safety architecture compared with traditional hardwired safety relays?

The technology is making machine manufacturers happier. Well, the whole idea is that having a drive with embedded safety is saving the machine manufacturer quite a bit because now you don't need an external safety relay with additional wiring—basically it's like the safety relay is embedded in your servo drive, so you have already eliminated one piece of hardware.

"Now, if you use hardwired safety to the drive, it works, no problem whatsoever. But you still have wiring coming in, so you are using copper. Then you must make sure that your electrical schematics are correct and that your electrician is doing all the work, which might require a lot of pulling cables," Gianotti said. "Now if you can bring the safety on the same bus interface, then you use a standard Ethernet cable and you have safety running on that Ethernet cable together with your standard communication protocol."

Reducing Downtime and Providing Operational Flexibility

When you have mounted equipment like a robotic arm or machines moving around the factory like AGVs or AMRs, you will inevitably have humans working near their robotic counterparts. Old school safety functions

The certification covers Elmo's Titanium servo drives for both industrial and harsh-environment applications, providing machine builders and system designers with advanced Functional Safety integrated directly into compact, high-performance servo technology.



Whenever a piece of equipment is running by itself, such as a robotic arm or autonomous vehicle, safety should be one of the main drivers. **(Image: Elmo Motion Control)**

would shut everything down the second a human operator triggered a sensor. Gianotti said by implementing more sophisticated safety features inside the drive today, you can change these parameters.

"You can parameterize the drive in such a way that when a human enters the working area and is ten feet away, I can reduce my speed by 50 percent and my torque by 50 percent. If a human gets closer, the speed and torque reduces another 25 percent. The robot never stops—he just keeps producing. In the past, we were shutting down everything and losing time to restart, now we can keep things moving in safer ways without interrupting production," he added.

The challenge the industry is currently facing is figuring out how to make everything safe according to the standards while minimizing productivity loss. It is no surprise that workers on deadlines with KPIs need to meet certain production levels. If the equipment fails or shuts down, they will do what they need to do to get production moving again.

"One of the greatest challenges is creating safety systems that are difficult to tamper with," Gianotti said. "We used to have a dead man's switch designed to automatically stop, disable or trigger if the human operator was physically removed from the controls and they could work around this safety feature simply by placing a piece of tape over the switch."

The operator could do whatever they needed to do without the machine realizing that it should stop or slow down. Gianotti mentioned this example because the technology has changed through the years. "Manufacturers have developed new sensors in which you cannot just keep it squeezed, you have to double tap it or apply and keep a certain amount of pressure (not too strong and not too light), which is much more difficult to replicate with a piece of tape."

Protecting Vital Machine Assets

Safety has become increasingly critical as collaborative robots, humanoids, AGVs, AMRs and other automated systems gain traction in manufacturing. As these technologies evolve, manufacturers must also address cybersecurity risks that could compromise functional safety.

It is difficult to imagine a more dangerous scenario than a cyber-attack disabling or weakening the safety checks on a collaborative robot, humanoid or autonomous vehicle. If a robot fails to slow down or reduce torque near human operators, the consequences could be severe.

"Functional safety itself needs to be protected from cyber-attacks the same way you protect your standard PLC or computer," Gianotti said.

Password protection for safety parameters will become increasingly important in drive manufacturing. Although current cybersecurity regulations primarily target controllers and industrial PCs, stricter requirements will extend to drives. Currently, we have customers for example, after the drive is parameterized, they proxy the USB port so nobody can physically access the drive or change parameters. Let us call this 'hardware cybersecurity,' if you will, preventing access to the device. Eventually, this will start being part of standards and official regulations as well," Gianotti said.

"Beginning in 2027, manufacturers seeking a CE mark to sell machinery in Europe will need to demonstrate compliance with cybersecurity requirements under the European Union's machinery regulations. Security measures such as password protection, which manufacturers have already used to safeguard machine safety, will therefore become mandatory. Europe is leading this regulatory shift, and I expect the United States to follow," Gianotti said.

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PTE

Less Is More

Ruland upgrades critical medical application through custom coupling design



Matthew Jaster, Director, Editorial Content

Ruland offers a complete range of servo couplings to match coupling performance to application requirements. **(Image: Ruland)**

When a major manufacturer of dialysis equipment began developing the next generation of one of its products, cost reduction became a key objective. The existing design had proven itself in the field, but the company believed there were opportunities to lower costs without sacrificing the reliability required in a critical medical application.

One area identified for review was a custom coupling used in a pump-and-valve assembly. The coupling had originally been designed in-house and was manufactured by a machine shop. While it performed well, it was expensive to produce and included features that exceeded the application's actual requirements.

To identify potential savings, the OEM engaged an engineering design firm that had previously worked with Ruland. The goal was to find a coupling that could deliver the required performance at the lowest overall cost.

The original coupling functioned similarly to an oldham coupling but was built from bronze with a metallic center element and custom dimensions. Because it was produced entirely as a custom-machined component, the OEM was paying for a specialized design without benefiting from the economies of scale available from a dedicated coupling manufacturer.

"This illustrates why it is important to work with a standards manufacturer from the beginning," said Chris Gumas, director of customer experience at Ruland. "When a company designs something themselves, they often over-design and over-build it. Manufacturers can really offer value in helping guide them to the cheapest option up front, so they do not spend additional engineering resources redesigning the product later."

The application itself was demanding. The coupling operates inside



Dialysis equipment for the medical industry.



Ruland D-bore couplings prevent slipping by engaging directly with D-shafting in precision motion control applications. **(Image: Ruland)**

> When a company designs something themselves, they often over-design and over-build it. Manufacturers can really offer value in helping guide them to the cheapest option up front, so they do not spend additional engineering resources redesigning the product later.

dialysis equipment used in hospitals or homes, connecting components within a pump-and-valve system that controls fluid movement during treatment.

Couplings have crevices, threads, and seals where biofilm can form and survive disinfection. Water and dialysate must meet strict microbiological limits for bacteria and endotoxins. Contaminated fittings in the water or dialysate path can lead to pyrogenic reactions, which cause fever and chills during treatment, and they contribute to chronic inflammation. The design of these fittings matters for disinfection. Smooth surfaces, few dead spaces and compatibility with heat and chemical disinfectants all affect how well they can be cleaned. Any fitting where fluid can sit without flowing is a particular concern.

Additionally, home hemodialysis and nocturnal dialysis make reliable couplings even more important. During these treatments a patient may be asleep or alone, without a nurse watching the lines. This has pushed the development of locking connectors, disconnection and leak sensors, and simpler, error-resistant connection designs. In short, couplings in dialysis are where mechanical reliability, infection control and human error all meet. That is why they get so much attention in device design, clinical protocols and maintenance programs.

Reliability is essential, and the coupling for this application had to satisfy two key requirements: zero-backlash for accurate valve positioning and a positive mechanical connection that would not slip.

The OEM used D-shaped shafts on both sides of the coupling to prevent slippage. While the shaft dimensions were non-standard, the design firm determined that several commercially available coupling styles could meet the performance requirements.

After evaluating multiple options, including bellows and jaw couplings, the team selected an oldham coupling. It provided the required zero-backlash performance while offering the most cost-effective solution for the relatively low-speed, low-torque application.

Ruland modified a standard oldham coupling with custom D-bores to match the existing shaft geometry. Because custom D-bores are a common request, the modification was straightforward and required no redesign of the larger assembly.

The result was a cost reduction of approximately $300 per coupling while maintaining the same level of performance and reliability. Given the OEM's annual usage of hundreds to thousands of units, the savings were substantial.

"When a coupling is overbuilt for the application, you are paying for performance you do not need," said Gumas. "By matching the coupling style and materials to the real requirements, we were able to maintain reliability while cutting costs dramatically."

Today, the modified oldham coupling continues to be used in multiple generations of the OEM's dialysis equipment. The project demonstrates an important engineering principle: the best solution is not always the most complex one. By selecting the right coupling for the application rather than the most robust coupling available, the OEM achieved significant cost savings without compromising performance.

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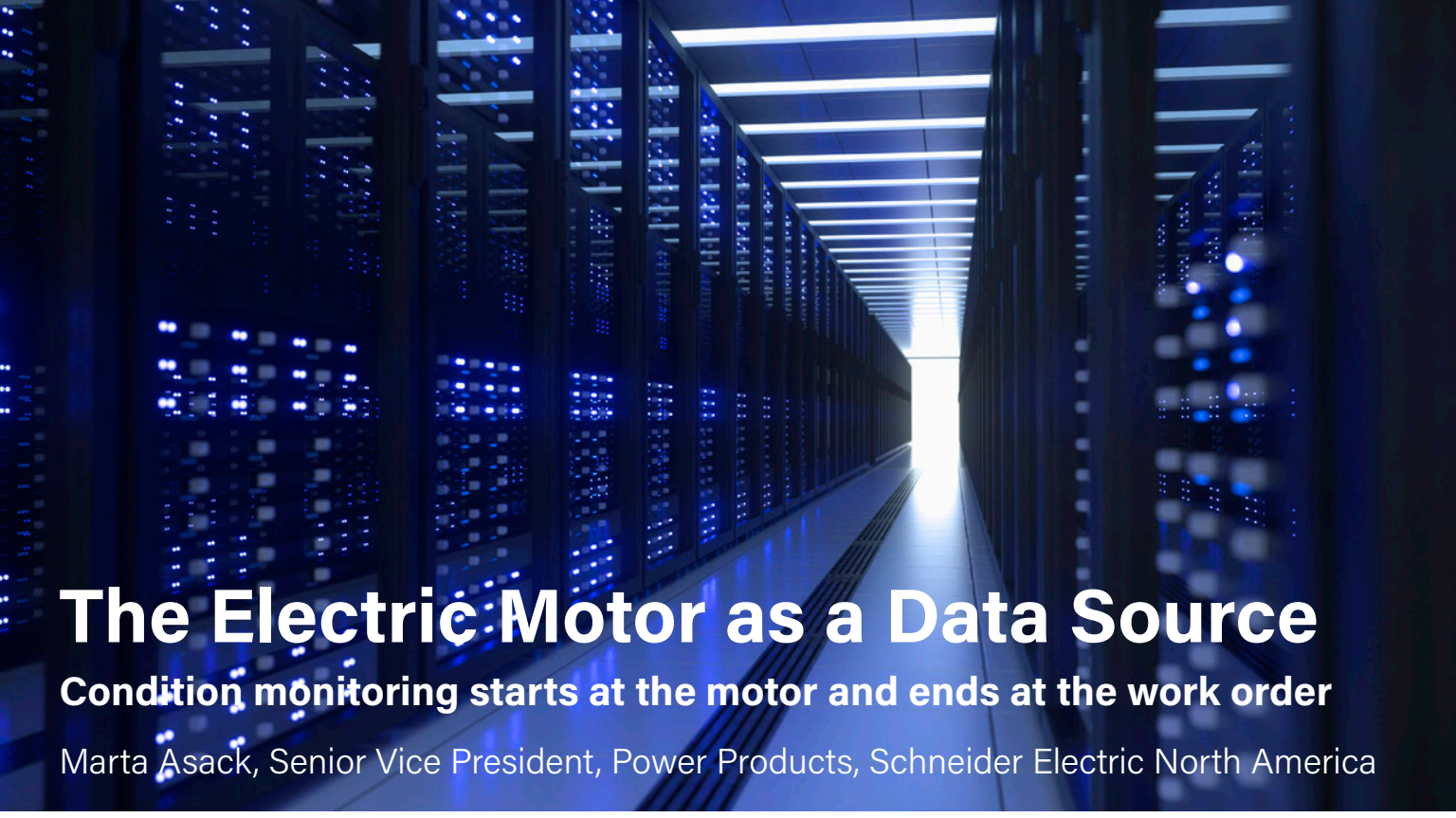


The Electric Motor as a Data Source

Condition monitoring starts at the motor and ends at the work order

Marta Asack, Senior Vice President, Power Products, Schneider Electric North America

Electric motors are critical to data center operations, powering cooling systems, pumps and other equipment.

At Automate in Chicago this June, I was asked what predictive maintenance involves and why it is happening now. When I started as an engineer designing control systems, we collected data all day long, and in many cases, we did very little with it. We had plenty of sensors and very little ability to turn what they collected into a decision in time to matter.

Computing speed, real-time data and artificial intelligence (AI) have since arrived together, and the value in motor data is now within reach for a plant of almost any size. The part I care most about has not changed. A plant can get into a loop of continuously monitoring everything, and if nobody takes the right action on what the data shows, the effort is wasted. That is how I look at condition monitoring. Start at the motor, and judge the program by what happens after the alert.

Why Condition Monitoring Should Start at the Motor

Power transmission is a mechanical world of shafts, gears, bearings and couplings, and nearly all of it is turned by an electric motor. The motor is the one component in that train that reports on itself. The equipment that starts it and protects it has to measure how hard the motor is working, every minute it runs. Every motor in a plant is a data source, whether or not anyone is reading it.

Electric motor systems account for 72 percent of industrial electricity consumption, according to the International Energy Agency's Electric Motor Systems Annex. That makes the motor the place where a plant's energy costs and its reliability risks meet. Ask a reliability engineer what fails first on a motor, and the answer is the bearings. It has been the answer in the industry's reliability surveys since the 1980s.

Mechanical problems downstream of the motor change how hard the motor has to work, and the motor's data reflects that. When a coupling goes out of alignment, or a gearbox starts to lose efficiency, the motor draws more current to do the same job. The same is true of a pump fighting a partial blockage or a conveyor with a seized idler. A trend on that data will usually show the change before a technician can hear or feel it on the machine. It works the other way too. A small voltage imbalance at the motor produces a current imbalance six to 10 times larger, and with it extra vibration, heat and wear on the coupling and the bearings.

What Motor Data Can and Cannot Tell You

Every condition monitoring program is trying to widen the same window: the time between the first sign that something is going wrong and the moment the asset stops doing its job. Inside that window, a repair is a scheduled job. Once it closes, the same repair becomes an outage.

A single reading rarely opens the window. The value is in the trend against a baseline: a motor that works a little harder each week to do the same job, or one that starts far more often than its duty cycle assumed. AI has sped that up. Instead of relying on a model of a healthy motor built by an engineer years earlier, the model keeps learning from the plant's own data, so a shift gets flagged while there is still time to schedule the repair.

The data also has limits. It will not tell you which bearing is wearing or why. Vibration analysis, thermography and oil analysis answer those questions. The electrical data tells those tools where to look and when, from equipment in the panel, with nothing mounted on the machine. It also catches what a vibration sensor cannot, such as a power quality problem or a slow rise in load that means the process itself has changed.

Energy is part of the same picture. A motor-driven process that uses more energy than its baseline to produce the same output has added resistance somewhere in the train. Plants usually track that number for the utility bill, and it is also one of the earliest health signals they own. Uptime and efficiency go hand in hand. With demand on the grid climbing, a kilowatt a plant does not waste helps its own cost structure and takes pressure off the grid.

Where Predictive Maintenance Programs Stall

In my conversations with plants, the programs that stall tend to share the same habits.

They start with the technology instead of the problem. As an engineer, I like the most accurate tool available, but the plant does not always need it. The first question is what problem the plant is trying to solve. The answer decides which data matters.

They try to replace the whole system. People get nervous about new techniques because they think they have to tear out what they have. The best solutions are modular: add a layer, a sensor, or an algorithm to the systems you run today, prove the value, and expand from there.

They ask for trust before earning it. Some customers keep their traditional maintenance schedule until they trust the new insight, others are ready to act on forecasts, and a few will let the model decide. All three are legitimate. The mistake is asking a crew to trust a prediction before the system has caught one real problem for them.

They forget the spare parts. Time-based maintenance meant carrying a lot of inventory. Predictive maintenance can bring that closer to just in time, but only if the prediction reaches the people who order parts and schedule the crew.

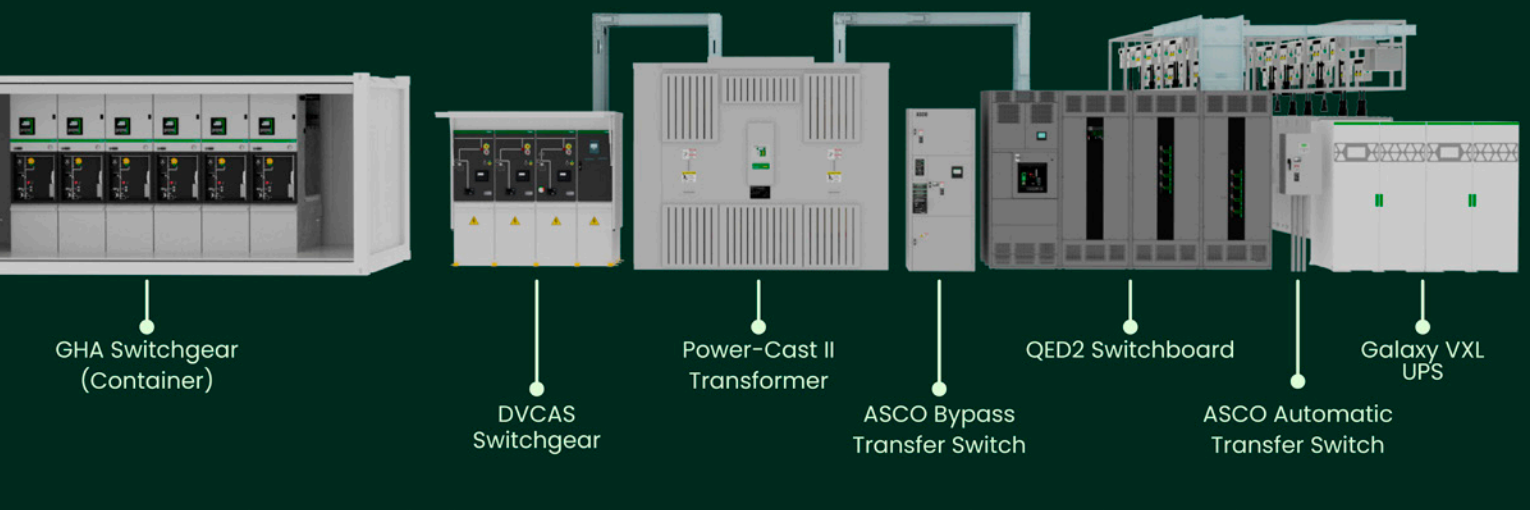
Each of these is a decision about how the plant will run the program, and the technology delivers far more once those decisions are made.

Building a Condition Monitoring Program That Lasts

Start with criticality. Not every motor deserves instrumentation. Find the handful of assets whose failure costs the most, whether in lost production, in damage to the coupling and gearbox behind the motor, or in risk to people.

Schneider Electric showcased motor and condition monitoring technologies at Automate 2026. **(Image: Matthew Jaster)**





An end-to-end power architecture: switchgear, transformer, transfer switches, switchboard, and UPS, working as one system to deliver reliable power to critical loads. **(Image: Schneider Electric)**

Baseline before you alarm. Instrument the asset, establish what normal looks like, alarm on deviation, and only then layer in prediction.

Close the loop into the work order system. An alert should turn into a work order in the CMMS with an owner and a due date. That connection to the way people already work is what makes the data pay off.

Keep protection local. Whatever monitoring gets added, the equipment protecting the motor should keep doing that job when the network does not.

Choose open systems. A motor that will run for 20 years should not be tied to one supplier's data format, and I say that as someone who sells the equipment. Equipment built on open standards can be read by analytics tools that do not exist yet, so the data outlives the supplier relationship.

For U.S. plants, there is now a standards reason as well. NFPA 70B, the standard for electrical equipment maintenance, went from a recommended practice to a standard in its 2023 edition. The 2026 edition recognizes continuous monitoring data as an input to the condition assessments that set maintenance intervals.

Retrofit First: Intelligent Motor Management for the Plant You Have

Most facilities are not starting from a blank sheet. They run equipment installed over the last 30 or 40 years, and the plant manager is usually fighting daily downtime. Nobody in that position wants to hear that they have to replace their controls to get started, and they do not.

The workforce makes the timing urgent in North America. A generation of experienced maintenance technicians is retiring, and many plants are short of people with the skills to integrate and maintain new technology. That means capturing the judgment of experienced people in data before they leave and choosing tools simple enough that a newer technician can commission, use and maintain them.

The retrofit path is more practical than most people expect. Modern motor management devices combine protection, control and monitoring in one unit and can be added to an existing motor control center one critical motor at a time. One example is TeSys Tera, a motor management system Schneider Electric introduced in North America in April 2026 for new installations and retrofits. It is designed to flag overheating, imbalance, electrical faults and mechanical degradation before they lead to an outage, and to share what it sees with the systems a plant uses today.

The biggest barrier I see is that plants do not know what they need. That is what an energy technology partner is for: helping a plant choose the few things that fit the problem it has and the infrastructure it owns, prove the value on a handful of critical motors, and grow from there. Customers who start at that scale come back and expand it.

Bearings will keep wearing and processes will keep changing. Condition monitoring does not change that, and no program should promise otherwise. It changes how early the plant knows and what it does with the notice. Corrective work lands in a planned window instead of arriving as an emergency.

We were collecting this kind of data when I started as an engineer 20 years ago. The computing, the connectivity, and the tools have since reached a price an ordinary plant can justify. The plants that come through the next decade of workforce turnover and grid strain in good shape will be the ones that started at the motor and finished at the work order.

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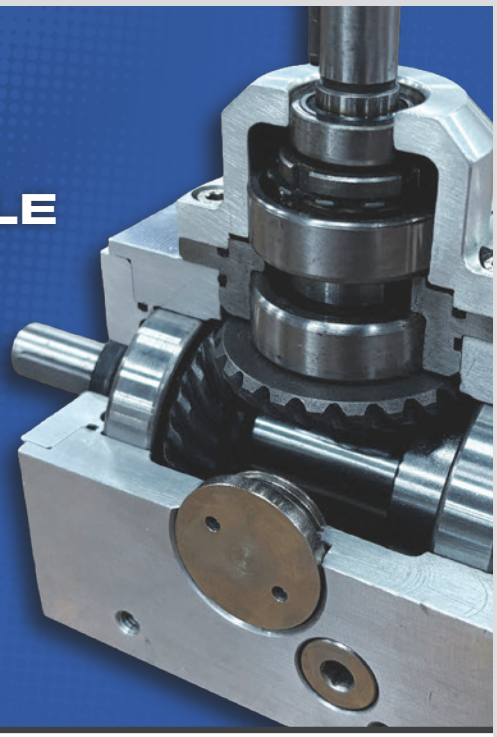

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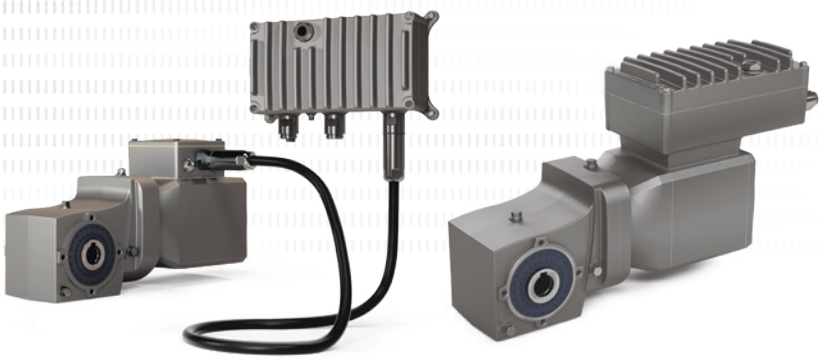

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Design of Low-Noise Powder-Metal Gears: From Mesh Excitation to System Response

Dr.-Ing. Philipp Kauffmann; Dr.-Ing. Markus Rüngeler and Preetham Jonnalagadda, M.Sc.

In battery-electric vehicles, the absence of combustion-engine masking noise increases the perceptibility of tonal transmission noise and exposes sources that are less prominent in conventional vehicles (Ref. 16). Gear-mesh-related components are particularly relevant at low and moderate vehicle speeds, where aerodynamic noise remains limited and tire-road noise does not necessarily dominate the overall sound field. As speed increases, the relative contributions of tire-road and aerodynamic noise rise, while the dominant interior-noise paths remain vehicle- and operating-condition dependent (Refs. 16, 17). As Figure 1 schematically illustrates, the main opportunity to reduce perceived gear whine lies in the operating range where gear noise remains acoustically exposed.

This article presents a design methodology for low-noise powder-metal intermediate gears in electric drive units, in which material properties, tooth microgeometry, and gear-body architecture are developed together as a single NVH concept.

Powder Metallurgy as an Enabler of Integrated NVH Design

Against this acoustic background, gear design must address both mesh excitation and the structural transmission mechanisms that lead to radiated sound. Powder metallurgy offers a particularly suitable platform for this task. Its inherent material damping can reduce selected resonance amplitudes, while its near-net-shape capability permits functional features to be integrated into the gear body with limited additional machining. Experimental and numerical investigations of alternative gear materials likewise show that material selection affects excitation and dynamic response and should therefore be linked to geometry-specific NVH optimization (Ref. 11). The resulting opportunity is not limited to replacing wrought steel with a powder-metal material. Instead, a low-noise solution can be built around the PM process by coordinating material properties, tooth-contact design, and structural architecture for the specified transmission system and duty cycle.

Figure 2 summarizes the NVH value chain from gear-mesh excitation to radiated sound and highlights the three principal design levers considered in this work. Loaded transmission error generates dynamic mesh forces that propagate through the gear body, shaft, bearings and housing, where interaction with structural modes can amplify the vibration before it is radiated as sound. Within this chain, microgeometry controls the excitation, gear-body architecture tailors the structural response and transmission path, and PM material damping influences the dissipation of vibrational energy. This framework illustrates why these effects should be considered jointly when developing a low-noise PM gear solution.

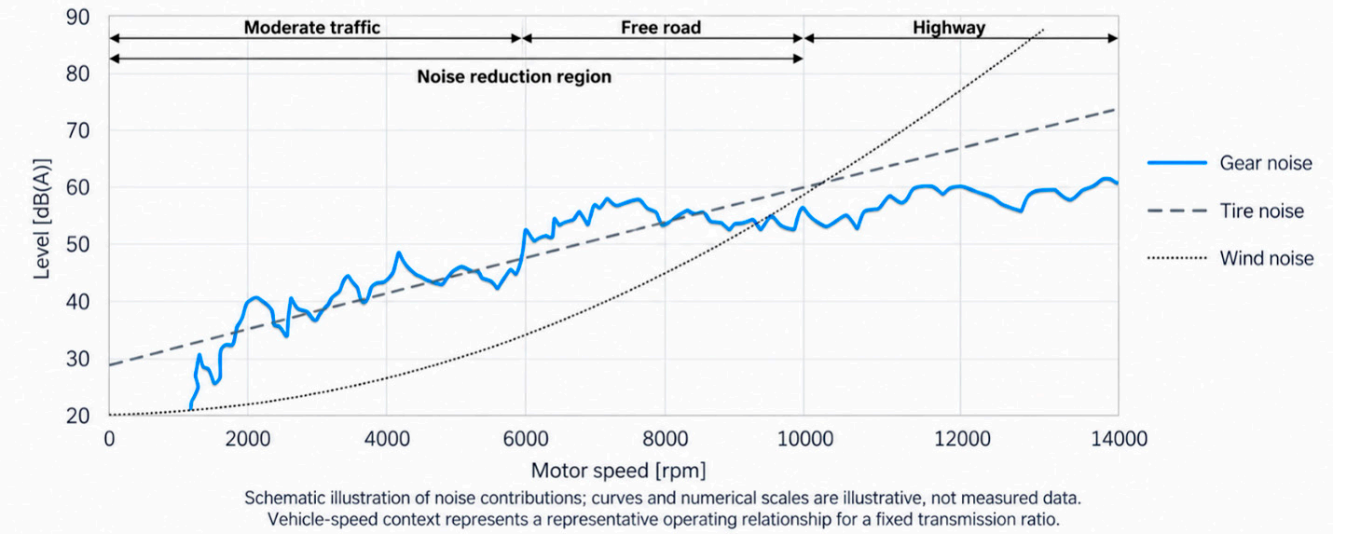

Figure 1—Gear, tire-road, and aerodynamic noise over the speed range of a battery-electric vehicle. Schematic only; curves do not represent absolute sound-pressure levels (Refs. 16, 17).

Excitation—Response Framework

Loaded transmission error is a principal source of gear-whine excitation. It is defined as the deviation of the actual relative motion of a loaded gear pair from ideal conjugate motion. The resulting waveform is governed by tooth and gear-body deformation, time-varying load sharing, tooth microgeometry, manufacturing deviations, and system misalignment. Loaded tooth-contact analyses that include measured profile deviations and mesh-stiffness effects provide suitable methods for quantifying these excitation mechanisms (Refs. 6, 9).

The resulting dynamic forces propagate along a structure-borne transmission path comprising the gear body, shaft, bearings and transmission housing. Each component contributes frequency-dependent stiffness, inertia, damping and coupling characteristics. Resonant amplification occurs when gear-mesh orders intersect structural natural frequencies of components within this structure-borne transmission path. The amplified vibration is transmitted to the housing, whose vibrating surfaces ultimately radiate sound. Gear NVH should therefore be analyzed as a coupled excitation-transmission-radiation problem, as also reflected in system-level e-drive studies combining structural and microgeometry optimization (Refs. 1, 5).

The speed-dependent gear-mesh excitation provides the link between transmission error and the structural

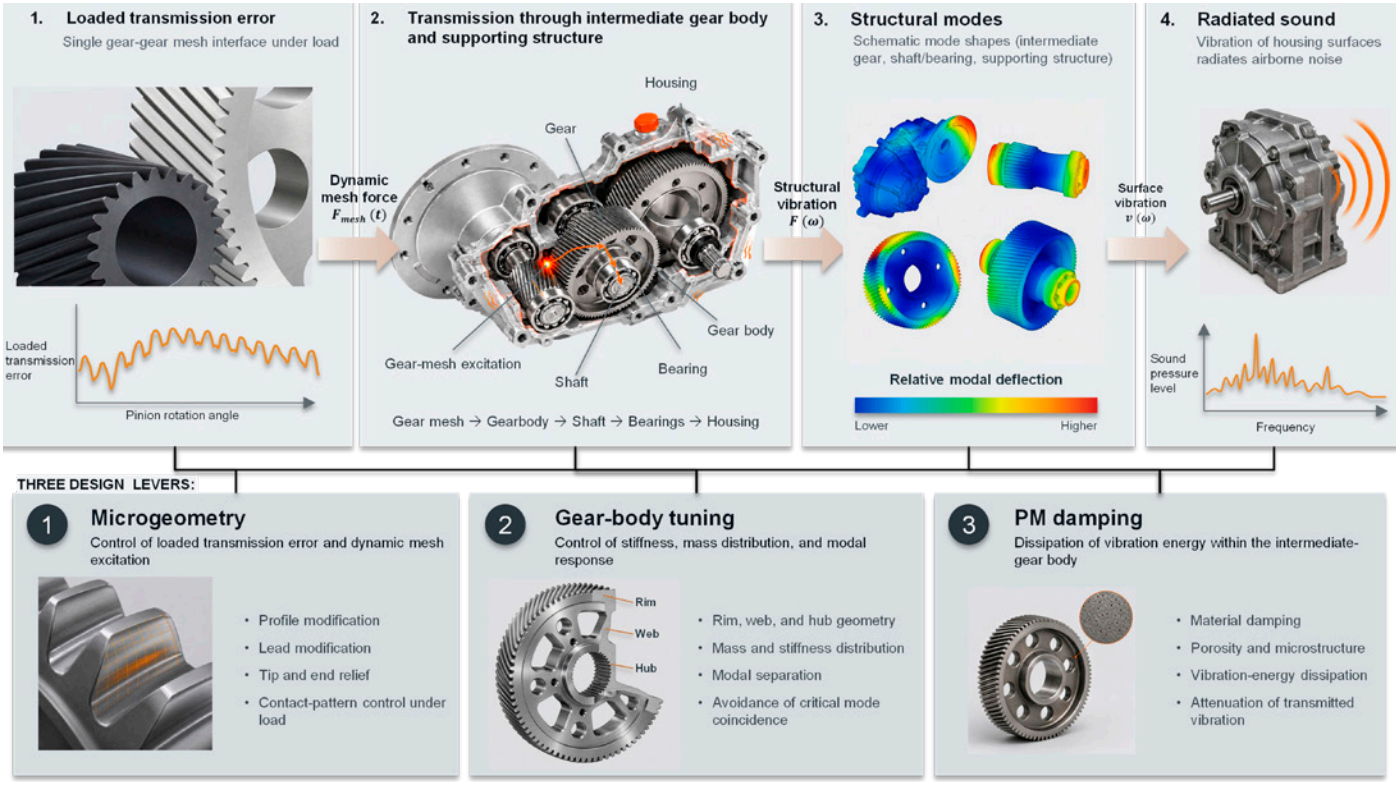

Figure 2—NVH value chain from gear-mesh excitation to radiated sound, showing the three PM design levers.

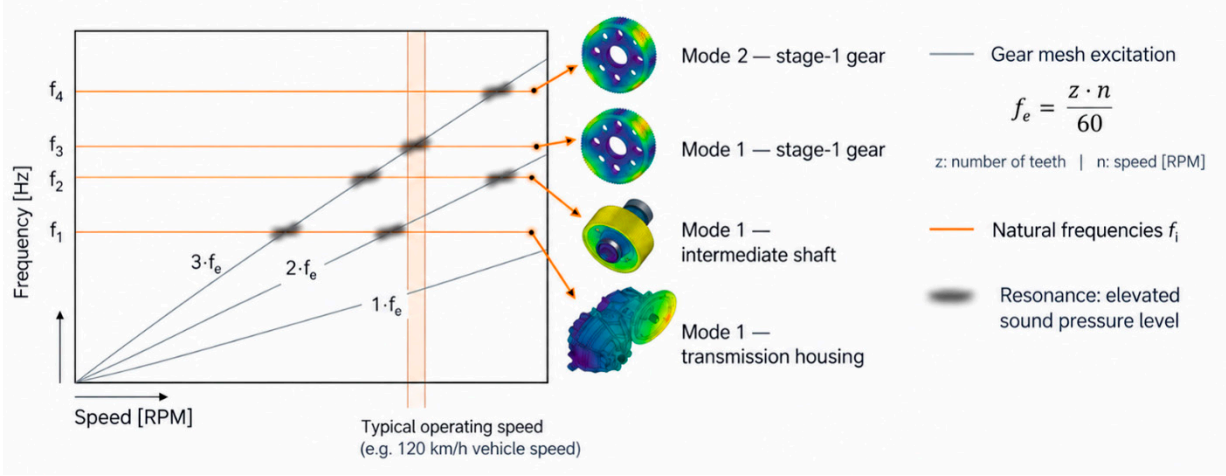

Figure 3—Campbell diagram of gear-mesh orders crossing natural frequencies of the housing, intermediate shaft, and first-stage gear.

response of the drivetrain. The fundamental mesh frequency is defined by the rotational speed and number of teeth, $fe = z \cdot n/60$, while higher harmonics arise from the periodic mesh-stiffness variation. As illustrated in Figure 3, these excitation orders increase linearly with speed and intersect the approximately speed-independent natural frequencies of the transmission housing, the intermediate-shaft bending mode, and the first-stage gear modes. At an order crossing, the corresponding structural mode can amplify the transmitted excitation and produce a local increase in sound pressure. The acoustic response therefore depends not only on the magnitude of transmission error but also on modal participation, damping and the location of the crossing relative to the operating-speed range. This Campbell-diagram interpretation provides the basis for evaluating how PM-related changes in mass, stiffness, and damping shift natural frequencies and modify resonance amplitudes.

Influence of Material Properties on Structural Dynamics

Residual porosity influences the effective elastic, inertial, and dissipative properties of sintered steels and can therefore be used as part of the NVH design concept. Compared with a wrought-steel reference of identical geometry, the transition to PM generally reduces component mass and effective elastic stiffness while increasing material damping through porosity-related internal friction. The lower stiffness changes loaded tooth compliance, time-varying mesh stiffness, load sharing, and consequently the amplitude and spectral content of gear-mesh excitation. The damping benefit and the excitation change therefore occur simultaneously and cannot be represented by a damping factor alone. Figure 4 summarizes the three material-property changes most relevant to the transition from wrought steel to PM: reduced mass, lower effective Young's modulus, and increased material damping.

Reviews and dedicated measurements of sintered materials substantiate the dependence of Young's modulus, damping, and other physical properties on total porosity and pore morphology (Refs. 4, 8). For sintered Astaloy 85Mo, tensile, compression, and hardness measurements further show that density, pore shape, and sintering conditions substantially affect Young's modulus, yield strength, ultimate tensile strength, ductility, and the difference between tensile and compressive behavior; models based only on spherical pores do not reproduce the measured response with sufficient accuracy (Ref. 15).

In a gear application, these property changes influence both the tooth-contact problem and the modal response of the complete gear-shaft assembly. High-density single-compaction technologies and secondary cold- or hot-forming processes can increase density and improve durability to the level required for high-performance gear applications, with the objective of meeting relevant wrought-steel benchmarks (Refs. 12–14). Prior work on highly loaded PM gears further identifies damping, lightweight design, stiffness-based geometry design, and manufacturing-related properties as interdependent elements of an integrated transmission solution (Ref. 14). The resulting properties depend on alloy composition, heat treatment, pore morphology, local densification and the manufacturing route. These parameters should therefore be characterized and incorporated explicitly into the design model so that the acoustic potential of the PM material can be used systematically.

The modal effect of a powder-metal gear depends on the spatial distribution of stiffness, mass and damping. For a bending mode dominated by the gear body, reduced effective stiffness tends to lower the modal frequency, whereas reduced mass tends to increase it; the

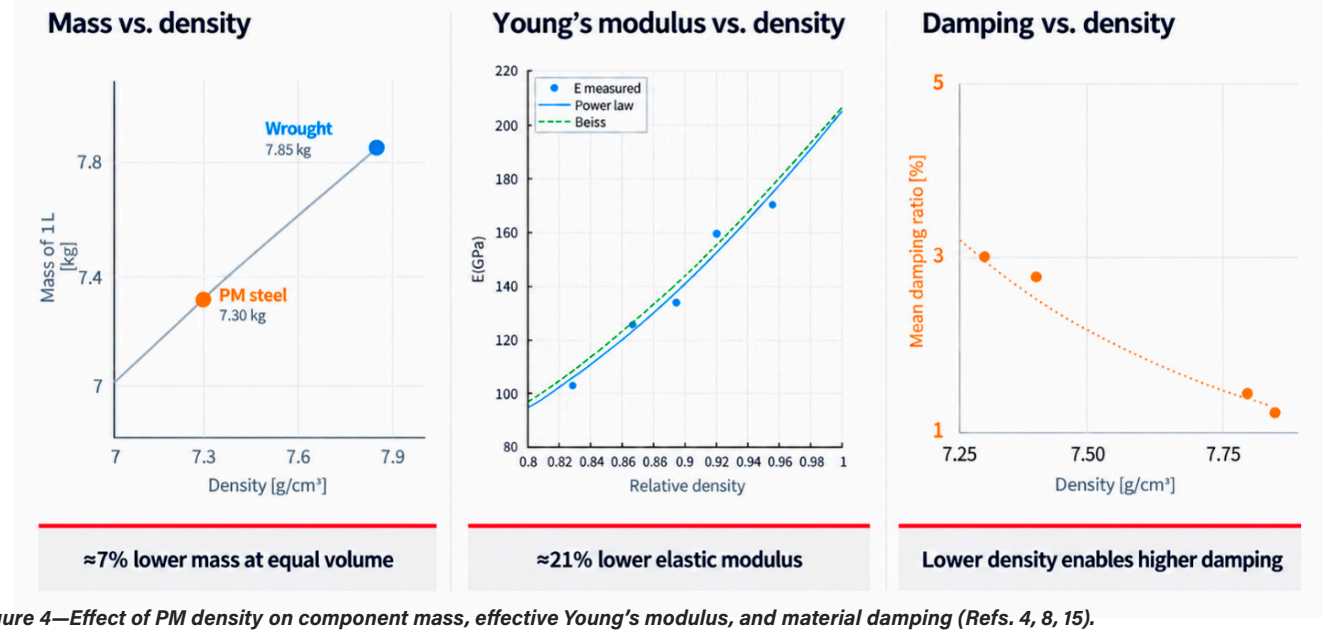

Figure 4—Effect of PM density on component mass, effective Young's modulus, and material damping (Refs. 4, 8, 15).

resulting frequency shift depends on the mode shape and on whether the gear body, shaft, or their coupling dominates the stored strain and kinetic energy. Increased damping can reduce resonance amplitude without necessarily moving the resonance. Shaft-dominated modes may respond differently because shaft stiffness remains approximately constant while the attached gear mass and body stiffness change. This mode-specific behavior provides a design space that can be exploited through coordinated material selection and body geometry. Mode shapes, modal participation factors, damping ratios and gear-shaft assembly frequencies should therefore be evaluated together. The measured benefit is expected to vary with torque direction, torque level, rotational speed, and the proximity of mesh orders to structural modes. Available system tests showed favorable PM behavior at selected partial-load drive conditions, but less favorable behavior under coast and in a high-speed region; the performance gap decreased with increasing torque. This pattern is consistent with simultaneous changes in loaded contact, mesh excitation, and resonance amplification rather than with a speed-independent material effect. The objective is to use the PM-specific property combination to reduce critical responses and move relevant resonances away from highly utilized operating regions.

Microgeometry Adaptation to Loaded Contact Conditions

The lower effective elastic modulus of PM changes loaded tooth deformation and load sharing relative to a wrought-steel gear. Consequently, flank corrections optimized for the steel reference cannot be transferred to the PM gear without verification. Profile relief, crowning, and lead corrections must be adapted to the PM-specific compliance, including the system-level deflections of shafts and bearings and the relevant drive, coast and torque conditions. The optimization must jointly consider loaded transmission error, contact pressure, tooth-root stress, manufacturing deviations and tolerance sensitivity (Ref. 10). The objective of the PM-specific microgeometry is to reduce mesh excitation to a level comparable to that of a conventionally manufactured gear with optimized microgeometry. Only when the excitation levels are comparable can a subsequent reduction in system response be attributed primarily to the higher material damping of PM.

Optimization should include representative torque levels and both drive and coast conditions. A parameter set that minimizes transmission error at a single operating point may perform less favorably elsewhere in the operating envelope. The applied workflow combines a coupled-slice contact model, Hertzian contact calculations, and reusable finite-element-derived gear-body compliance. This hybrid formulation enables broader parameter exploration, although its assumptions and validity range must be verified against higher-fidelity calculations and experimental data. Computational efficiency is relevant only if the model resolves the design differences required for the engineering decision.

Gear-Body Architecture as a Structural Design Variable

The web and rim determine local compliance, modal stiffness, inertia distribution, damping utilization and coupling to the shaft. Powder-metallurgical near-net-shape processing enables voids, ribs, curved load paths, and local section variations to be integrated directly into the gear body. These features can be designed to modify both loaded tooth behavior and the structure-borne transmission path through the transmission. Gear-body optimization studies demonstrate the potential of modified and topology-optimized architectures to reduce mass and vibration through targeted redistribution of stiffness and inertia (Refs. 2, 3, 7). This manufacturing capability is a central element of the proposed NVH solution: it allows the gear body to be developed around the characteristic properties of the PM material instead of reproducing conventional wrought-steel geometry. PM-specific investigations further demonstrate that near-net-shape production can be combined with local surface densification to preserve geometric freedom while increasing the load-bearing capability of the tooth surface (Refs. 12, 13). Tooling, compaction, density distribution, ejection, rolling, and subsequent processing therefore define a coupled product-process design space and should be included from the beginning of the optimization.

The description of a design as providing a “longer structure-borne transmission path” may be useful conceptually but does not, by itself, demonstrate attenuation. A curved or interrupted load path changes compliance and modal behavior and may also introduce an undesired resonance. The relevant criterion is whether the modification reduces the response transmitted to the bearings and radiating surfaces under the prescribed excitation. Modal analysis, frequency-response calculations, and structure-borne transmission-path measurements provide stronger evidence than a qualitative representation of the vibration path. Similarly, a pocket or void should not be described as trapping vibration unless the underlying mechanism has been demonstrated experimentally or numerically.

A Campbell diagram relates structural eigenfrequencies to speed-dependent mesh orders. For each candidate design, relevant order crossings should be identified within frequently used torque-speed regions and assessed with respect to modal excitation and coupling to the housing. An increase in natural frequency is not intrinsically beneficial, because it may shift an order crossing into another relevant operating region or toward a different harmonic. The objective of optimization is therefore a favorable system response over the prescribed duty cycle while satisfying strength, mass and manufacturing constraints.

Integrated Use of All PM Design Levers

The transition from wrought steel to PM should be treated as a coordinated redesign rather than as an isolated material substitution. Three design levers must be addressed simultaneously: the PM material and manufacturing route define density, elastic modulus, damping, strength, and geometric freedom; PM-specific microgeometry restores the loaded contact conditions and mesh-excitation level; and the gear-body architecture tailors modal frequencies, structural coupling, and the structure-borne transmission path. If one lever remains optimized for the wrought-steel reference, it can limit or mask the benefit provided by the others. Higher material damping can reduce system response only after the excitation level has been controlled, while a favorable gear-body mode shift remains effective only if the associated order crossings lie outside critical operating regions.

Figure 5 was created using an NVH database based on approximately 300 NVH test results from system-level EDU testing, comprising more than 60,000 data points. It compares the frequency-dependent NVH response of lower-density PM gears with a wrought-steel reference, grouped according to whether the tooth microgeometry was adapted to the PM-specific compliance. Replicate measurements were averaged before comparison, and results are reported as mean noise differences within the indicated mesh-frequency bands. The plotted quantity is ΔdB(A) = PM dB(A) − wrought-steel dB(A); negative values indicate lower noise with PM, while positive values indicate higher noise.

Without PM-specific microgeometry optimization, the mean difference ranges from −0.66 dB(A) in the 0–1 kHz band to +2.11 dB(A) in the 8–9 kHz band, showing that a material substitution alone does not provide a consistent acoustic benefit. With adapted microgeometry, all reported differences are negative. The reductions range from −0.08 dB(A) in the 0–1 kHz band to −7.40 dB(A) in the 9–11 kHz band, with particularly favorable results above 3 kHz.

The comparison indicates that the acoustic potential of the PM configuration is unlocked only when the tooth microgeometry is adapted to its material properties and loaded compliance. However, the two rows represent complete implementation groups rather than controlled same-design pairs, so the observed difference cannot be attributed to microgeometry alone. The results therefore support the integrated design approach: PM material properties, tooth microgeometry, and gear-body architecture must be engineered together to achieve a consistently favorable NVH response across the relevant frequency range.

Development Case: Distinction Between Acoustic Performance and Robustness

The development case followed a staged, PM-centered design approach. Gear-body concepts from a PM-feasible design library were evaluated against the application-specific requirements, including resonance interruption at critical frequencies, mass and stiffness targets, and strength and package constraints, and were refined where required. The tooth microgeometry was subsequently optimized for the PM material properties and the stiffness of the selected gear body, compensating for load-dependent stiffness variations across the relevant operating conditions.

The resulting concepts were then assessed at system level to determine not only their absolute acoustic performance, but also the robustness of their NVH behavior. A concept may achieve the lowest measured noise at selected operating points and still show large scatter, insufficient separation from structural resonances, or a strong dependence on operating conditions. To distinguish between acoustic performance and robustness, the NVH design fingerprint characterizes the intrinsic acoustic behavior of a gear-body concept after operating-point effects such as torque, frequency and mesh order have been removed from the measured data. Instead of relying on a single noise value, it rates each concept against five individual criteria and one composite score that together describe how quiet, stable, predictable, resonance-safe and transferable a design is. Comparisons are only made within the same project and, where relevant, within the same material group.

Noise difference: PM minus wrought steel [dB(A)], averaged across projects by frequency band.

NEGATIVE = LOWER NOISE WITH PM POSITIVE = HIGHER NOISE WITH PM 0 = equal – = no reported value

Design changes / frequency (kHz)	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–11
G1: Without microgeometry optimization for PM	-0.66	-0.42	-0.35	-0.29	0.83	-0.21	0.76	0.54	2.11	1.45
G2: With microgeometry optimization for PM	-0.08	-2.24	-1.79	-3.01	-3.60	-0.73	-3.75	-5.26	-2.53	-7.40

Figure 5—Mean noise difference, PM minus wrought steel, by mesh-frequency band, with and without PM-specific microgeometry. Negative values indicate lower noise with PM.

The five individual criteria and one composite score are defined as follows:

Acoustic performance: Describes the absolute residual noise level of a concept after operating-point effects have been removed. A high score indicates that the gear body itself transmits and radiates less mesh excitation energy.

Frequency stability: Describes how evenly the acoustic response is distributed across the frequency range, without pronounced local spectral peaks. A high score indicates a smooth spectrum, whereas a low score points to distinct tonal peaks that typically require microgeometry or structural refinement.

Repeatability: Describes the scatter of the residual noise level between repeated tests, test conditions, and parts, expressed as residual standard deviation. A high score indicates a predictable NVH behavior that is less sensitive to unit-to-unit variation.

Resonance safety: Describes how far the operating points lie from structural natural frequencies, assessed by the share of points within ±50 Hz of a natural frequency and the mean modal separation. A high score indicates a low risk of dynamic amplification and mode crossing.

Operating independence: Describes the combined sensitivity of the noise level to speed, torque and frequency, expressed in dB per standard deviation. A high score indicates that the acoustic behavior depends only weakly on the operating condition and is therefore more likely to transfer to other applications.

Overall fingerprint: Combines the five individual criteria into one project-normalized score that summarizes the overall NVH quality of a concept. It supports ranking, but it does not replace the individual criteria, which reveal the specific strengths and weaknesses of a design.

Seven physically tested gear-body concepts were evaluated using the NVH design fingerprint. The assessment is based on the aforementioned NVH database. To protect proprietary design information, the concepts are anonymized. Table 1 reports the project-normalized rank of each concept for the five individual criteria and for the overall fingerprint. A rank of 1 represents the most favorable result. Comparisons were performed only within the respective project and, where applicable, within the same material group.

Concept 1 achieves the highest overall fingerprint rank. It ranks first in acoustic performance, repeatability, and resonance safety, while placing third in operating independence and fourth in frequency stability. This combination indicates a favorable balance between low residual noise, predictable behavior, and limited susceptibility to resonance-related amplification. Its comparatively weaker frequency-stability result nevertheless points to localized spectral variation that may benefit from further microgeometry optimization or structural refinement.

Concepts 2 and 3 share the second-highest overall rank but with different profiles. Concept 2 leads in repeatability, resonance safety, and operating independence, demonstrating robust behavior despite weaker acoustic performance and frequency stability. Concept 3 leads in frequency stability and ranks second in operating independence but performs less favorably in acoustic performance and resonance safety. This contrast highlights the importance of considering the individual criteria alongside the overall fingerprint.

Concepts 4 to 7 show greater trade-offs. Concept 4 combines strong acoustic performance with weaker repeatability and operating independence, while Concept 5 performs well in frequency stability but less favorably in resonance safety and operating independence. Concepts 6 and 7 show predominantly mid-to-lower rankings, with Concept 7 ranking lowest overall.

Based on this assessment, Concept 1 provides the strongest overall basis for further development. The next optimization step should preserve its favorable acoustic performance, repeatability, and resonance safety while improving frequency stability and maintaining low sensitivity to operating conditions. The fingerprint assessment addresses NVH behavior only. Durability, dimensional stability and manufacturing feasibility must therefore be evaluated independently before the concept can be considered suitable for transfer to series production.

Design	Acoustic performance	Frequency stability	Repeatability	Resonance safety	Operating independence	Overall rank
Concept 1	1	4	1	1	3	1
Concept 2	5	6	1	1	1	2
Concept 3	6	1	3	5	2	2
Concept 4	2	3	6	3	7	4
Concept 5	3	2	4	7	6	5
Concept 6	4	5	6	3	4	6
Concept 7	7	7	5	6	5	7

Table 1—Project-normalized ranks of seven anonymized gear-body concepts on five NVH criteria and the overall fingerprint (1 = most favorable).

Conclusions

Powder metallurgy can form the technological basis of a low-noise gear solution when its material and manufacturing characteristics are used as coordinated design levers. Material damping provides a mechanism for reducing critical resonance amplitudes, while near-net-shape capability enables the gear-body architecture to be tailored to the required stiffness, inertia distribution and vibration-transfer behavior. Tooth microgeometry can then be adapted to the PM-specific compliance so that mesh excitation and structural response are optimized together. Efficient contact models and simulation-based models expand the accessible design space, and system-level measurements quantify the resulting acoustic performance. With PM-adapted microgeometry, the evaluated configurations show lower mean noise than the wrought-steel reference in every reported frequency band, with differences from −0.08 to −7.40 dB(A). The resulting PM-centered approach combines acoustic level, robustness, mass, durability, and manufacturability within a single engineering framework and provides a practical pathway toward low-noise intermediate gears for electric drive units.

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Dr.-Ing. Philipp Kauffmann is Director of Research and Innovation at Johnson Electric, specializing in powder metallurgy, gear technology, advanced materials, hydrogen technologies, and sustainable manufacturing. He holds a doctorate from RWTH Aachen University and has more than 15 years of industrial experience developing technology for electric mobility and next-generation applications.



Dr.-Ing. Markus Rüngeler is a Lead Engineer at Johnson Electric, specializing in automotive drivetrain engineering, gear testing, and product validation. He holds a doctorate from RWTH Aachen University and has more than 10 years of industrial experience working on gear and differential systems, powder metallurgy, and structural and acoustic optimization.



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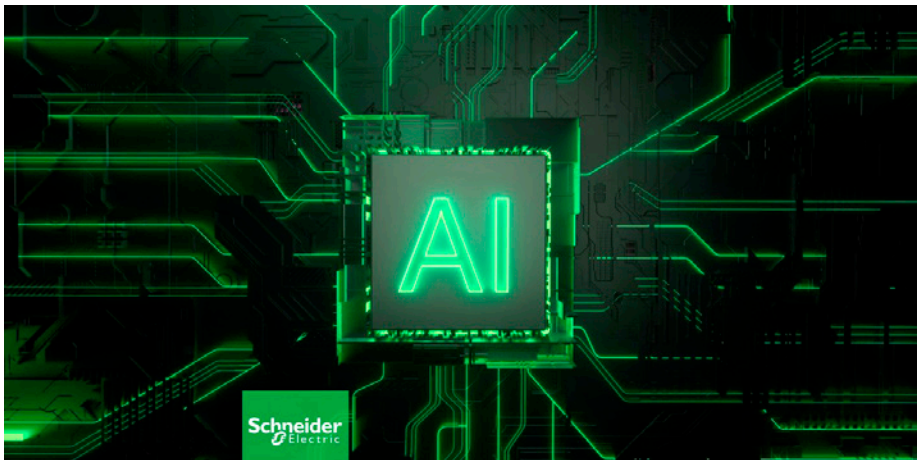
SCHNEIDER ELECTRIC
Announces Physical AI Strategy With NVIDIA and HPE



Schneider Electric has announced a strategic collaboration with NVIDIA and HPE to accelerate the adoption of Physical AI across process and heavy industries.

While much of today's Physical AI conversation is focused on robotics, humanoids and autonomous machines, process industries face a distinctly different challenge. Operators must manage complex, continuous operations where reliability, safety, cybersecurity and energy efficiency are critical to performance. Yet until now, there has been no clear blueprint for how Physical AI can be practically applied across these complex environments.

Schneider Electric, NVIDIA & HPE share a vision to bring AI closer to industrial operations, embedding intelligence directly within the environments where decisions are made and value is created. As an initial demonstration of this vision, the companies are today introducing Industrial AI Agents at the Edge.

The solution combines HPE Private Cloud AI, co-engineered with NVIDIA within the HPE AI Factory with NVIDIA portfolio Schneider Electric's deep operational technology expertise to enable organizations to securely deploy and scale AI applications at the industrial edge, bringing real-time intelligence closer to critical operations while maintaining control over sensitive data, security and costs.

Many industrial organizations continue to face challenges when scaling AI across operational environments. Requirements around data governance, cybersecurity, operational performance and AI deployment can create barriers to broader adoption. By operating at the edge, the solution helps address three challenges that continue to limit industrial AI at scale:

- Data sovereignty. Critical operational data is often too valuable, sensitive or regulated to move beyond operational boundaries. HPE Private Cloud AI provides the secure foundation for Industrial AI Agents at the Edge, enabling organizations to deploy AI close to operations while maintaining control, security and compliance.
- Cybersecurity. Increased connectivity can introduce additional risk across industrial and critical infrastructure environments. HPE Private Cloud AI reduces the attack surface by keeping and processing the data close to its source.
- AI consumption costs. As AI usage grows, cloud-based inference, data transfer and token-related costs can increase, creating challenges for organizations looking to scale AI across sites, assets and operations. Deploying AI at the edge with HPE Private Cloud AI can help reduce some of these costs while providing greater control over where and how AI workloads are executed.

Through Schneider Electric's EcoStruxure Industrial Insights apps customers can deploy, manage and govern multiple Industrial AI Agents through a single environment, simplifying lifecycle management, security oversight and maintaining full control of critical operations and infrastructure.

The first Industrial AI Agents focus on operational technology monitoring, cybersecurity and energy optimization. Their practical application can already be seen in industrial environments with companies such as CMPC Chile.

Operational Technology Monitoring System in Production: CMPC

The foundation for this next step is already proven at CMPC Chile, part of Empresas CMPC S.A., one of Latin America's largest pulp, paper and packaging producers. For the past three years, CMPC Chile has used Schneider Electric's OTMS in production to monitor the health and availability of control systems across its continuous pulp and paper operations.

OTMS provides CMPC's teams with a unified view of control systems, servers, workstations and switches, helping specialists identify emerging issues earlier, diagnose problems faster and establish clearer maintenance priorities. This proven deployment demonstrates the value of OTMS as a control-system monitoring solution and provides a strong operational foundation for the future introduction of Industrial AI Agents, with the potential to accelerate investigation and decision-making while keeping people in control of critical action.

The first three Industrial AI Agents at the edge:

- OT Monitoring Agents: Combines real-time operational data, equipment configurations, process topology, alarms, maintenance history and engineering context to understand the physical state of industrial operations. The agents identify emerging issues, reasons about likely operational impacts, recommends or initiates corrective actions, and verifies that the intervention delivers the expected physical outcome.
- Cybersecurity Agents: Correlates network activity, control system behavior, asset configurations, operational events and process context to detect abnormal conditions. The agents assess potential impacts on industrial operations, recommends or executes response measures, and validates that systems have returned to a secure and stable state.
- Energy Optimization Agents: Integrates process data, energy consumption patterns, equipment performance, operating conditions and production requirements to understand how energy is used across industrial operations. The agents identify optimization opportunities, recommends or implements adjustments, and verifies the resulting impact on energy efficiency, operational performance and sustainability outcomes.

"The next generation of industrial innovation will be driven by intelligence embedded directly into industrial operations," said Gwenaelle Huet, executive vice president, industrial automation, Schneider Electric. "While much of today's focus is on autonomous machines, we see a significant opportunity to apply Physical AI to the industrial systems that power the world's critical industries. Together with NVIDIA and HPE, we are bringing together expertise in automation, AI and edge computing to help customers transform operational data into action, improving resilience, efficiency, cybersecurity and sustainability while laying the foundation for more autonomous industrial operations."

"Industrial operations generate vast amounts of data, but turning that data into action remains one of industry's biggest challenges. By combining NVIDIA Nemotron open AI models and HPE Private Cloud AI, a turnkey AI factory solution, with Schneider Electric's industrial expertise and OTMS platform, Industrial AI Agents can monitor, reason and optimize operations in real time, accelerating the path to Physical AI for process industries," commented Sri Kodali global head of Developer Relations–Energy and Utilities at NVIDIA.

"Industrial organizations see real opportunities to use AI, and they want to be sure their sensitive data and critical systems will remain protected. Through our collaboration with NVIDIA and Schneider Electric, we're helping customers use HPE Private Cloud AI to bring AI closer to where their data is generated and decisions are made. This gives customers a way to expand AI use across their facilities while maintaining the security, privacy and control their businesses require," said Alexia Clements, SVP, Hybrid Cloud Solution Sales at HPE.

"For the past three years, OTMS has helped us improve visibility into the health and availability of our control systems. In continuous industrial operations, identifying issues early is critical to protecting production and avoiding costly disruption. Looking ahead, we see significant potential for AI Agents to build on this proven foundation, helping our specialists investigate issues faster and move more effectively from insight to action, while keeping people in control of critical decisions," said Matías Jory, digital and process manager, industrial operations vice-presidency, CMP.

Together, Schneider Electric, NVIDIA and HPE are creating the foundation for the next generation of industrial operations, where intelligent systems can continuously monitor, reason and optimize performance. Over time, these capabilities will help automate the automation, enabling safer, more efficient and increasingly autonomous operations across process industries.

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SCHAEFFLER Opens Lighthouse Factory in China



Schaeffler has opened a state-of-the-art lighthouse factory for humanoid robotics in Taicang, China. It houses an intelligent assembly line, a training and data acquisition center, a platform for digital twins, and a data center across approximately 7,500 square meters of floor space. The building covers the entire process from testing of individual robot skills to application in the actual manufacturing environment, showing what "humanoids making humanoids" looks like in practice: humanoid robots assembling key joint modules—including actuators—for the next generation of humanoid robots. The lighthouse factory marks the start of mass production of these components for Schaeffler and offers customers and partners the opportunity to train and test physical AI systems in actual industrial conditions. It therefore serves to drive adoption of humanoids in industry. Schaeffler's business also reflects the booming demand in this growth field: The company recently announced the acquisition of two new customers from the Greater China

region in Q3 2026. With this, global incoming orders for humanoid robotics rose to some 400 million euros.

Dr. Jochen Schröder, chief operating officer of Schaeffler AG, said: "Schaeffler wants to shape the production of the future and become a leading supplier and preferred technology partner for humanoid robotics. With the lighthouse factory in Taicang, we are creating something that has never before been seen in Schaeffler's global network: a closed manufacturing loop where humanoids assemble components for humanoids. In the lighthouse factory, we combine decades of manufacturing expertise with physical AI and digital twins. With it, we are expanding our capabilities for key robot components and taking humanoid robotics from theory to industrial practice."

At the heart of the lighthouse factory is an assembly line developed by Schaeffler for key components of humanoid robots, including linear and rotary actuators. Six humanoids work together at five stations. They stage and sort parts, join them, and inspect, label, and package them. A digital twin acts as a virtual replica that mirrors the actual line processes in real time. Sensors record parameters such as assembly accuracy, individual work step duration, energy consumption, and asset condition. Changes can be digitally tested and optimized before being implemented in the actual manufacturing processes. This leads to significantly shorter development times and more stable and reliable production.

At the same time, Schaeffler trains humanoid robots for industrial tasks in the training and data acquisition center. Tasks include visual inspection of parts, packaging, material handling/transport, container moving, and line-side material replenishment. The training environments are oriented toward the actual conditions in Schaeffler's approximately 100 manufacturing plants. This means that the learned skills can be tested and fine-tuned right on the assembly line. Robot performance is continuously improved through the use of linked data from training, simulation, and production.

Dr. Yilin Zhang, regional CEO Greater China at Schaeffler, said: "China's humanoid robotics industry is entering a fast growth period. As a motion technology company, Schaeffler is accelerating the development of China's humanoid robotics ecosystem by leveraging its local capabilities in research and development, manufacturing and industrial collaboration. The opening of the Taicang lighthouse represents another important move in Schaeffler's long-term commitment to China and business development in humanoid robotics."

schaeffler.com

SKF Opens Ceramic Process Lab in the Netherlands



Annika Ölme, CTO and senior vice president, technology development, SKF, and H.E. Julius Liljeström, Swedish Ambassador of the Netherlands took part in the grand opening of the Ceramic Process Laboratory (C-Pro Lab).

SKF recently announced the opening of its new state-of-the-art Ceramic Process Laboratory (C-Pro Lab) at its R&D Center in Houten, The Netherlands. This capability strengthens SKF's technology leadership across the complete ceramic manufacturing value chain, from raw material powder processing to high-performance component engineering, boosting the global adoption of advanced hybrid bearing technology.

As industries transition toward electrification and higher energy efficiency, demand for hybrid ceramic bearings is accelerating rapidly. By combining high-grade steel rings with silicon nitride rolling elements, hybrid bearings offer superior electrical insulation, lower weight, and reduced friction compared to traditional all-steel alternatives.

"Ceramic and hybrid bearing technologies are essential enablers for clean and reliable rotation in next-generation industrial electrical applications. The C-Pro Lab enables full mastery over the end-to-end ceramic process. This allows us to innovate faster, optimize material performance, and accelerate the commercialization of high-performance hybrid solutions for our customers globally," said Annika Ölme, CTO and senior vice president, technology development.

The C-Pro Lab serves as a global competence center within SKF's research and technology development organization enabling end-to-end optimization of ceramic technology. By bringing powder formulation, compaction, sintering, and surface finishing all together, SKF researchers can rapidly prototype new material compositions, optimize microstructures, and enhance process efficiency for high-volume manufacturing.

Hybrid ceramic bearings play a vital role in solving critical operational challenges across rapidly expanding sectors, including industrial automation, aerospace, and high-speed machinery. Driven by global demand for electrification, higher energy efficiency, and operational reliability, these sectors increasingly rely on ceramic technology to prevent electrical erosion in high-speed electric motors, cut friction by up to 50 percent, and deliver extreme-temperature reliability in demanding environments.

The official opening brought together customers from key industries, including railway, aerospace and drives, alongside other key stakeholders and H.E. Julius Liljeström, Swedish ambassador of the Netherlands, highlighting the importance of close customer collaboration in advancing industrial innovation and sustainable technology.

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January 18–21

PowerGen 2027



PowerGen (Salt Lake City) is the premier networking and business hub for power generation professionals and solution providers. It unites power producers, utilities, EPCs, consultants, OEMs and large-scale energy users. As the industry evolves toward cleaner and more sustainable energy, PowerGen fosters a progressive environment for both established professionals and new energy leaders driving the transition to a more sustainable future. A surge in data centers, industrial expansion, and electrification is reshaping power generation planning across North America.

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February 9–11

AIoT World Expo



The AIoT World Expo (Ft. Lauderdale, FL) explores the potential of intelligent machines, prescriptive analytics, sensor driven analytics and block chain solutions. Attendees learn about IoT technologies that are driving the transformation in manufacturing, supply chain and operations. Attendees include implementors, manufacturing companies, supply chain professionals, service providers, IoT manufacturers and more. Topics include smart mfg, smart cities, connected vehicles, machine learning, sensors, cybersecurity, data analytics and more. The show features dual tracks including "AIoT Solutions and Services" and AIoT Applications and Vertical Markets."

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February 17–19

MDSM 2027



Motor, Drive Systems and Magnetics (MDSM), Orlando, features the latest technical advancements in motor, drive systems, motion control, magnetic applications, technology and rare earth materials. This is an opportunity for professionals to hear content in design, efficiency, and application advancements in automation, robotics, manufacturing, utilities, automotive, medical, consumer, aerospace and defense industries. Motor & Drive Systems is focused on the latest technical advancements impacting the design, integration, and efficiency of motor, drive systems, and motion control.

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February 23–25

Additive Manufacturing Strategies 2027



The Additive Manufacturing Strategies conference (New York) brings together AM stakeholders from all over the world. AMS includes panels and keynotes on topics most critical in the fast-growing world of additive manufacturing. Bringing together the industry's leaders in a contained networking environment makes AMS the place for startups to access capital, for financial institutions and investors to sharpen their radars, and for the AM industry to focus on the business of AM. Speakers have included experts from Stratasys, EOS, Metal Powder Works, AMT, SME and more.

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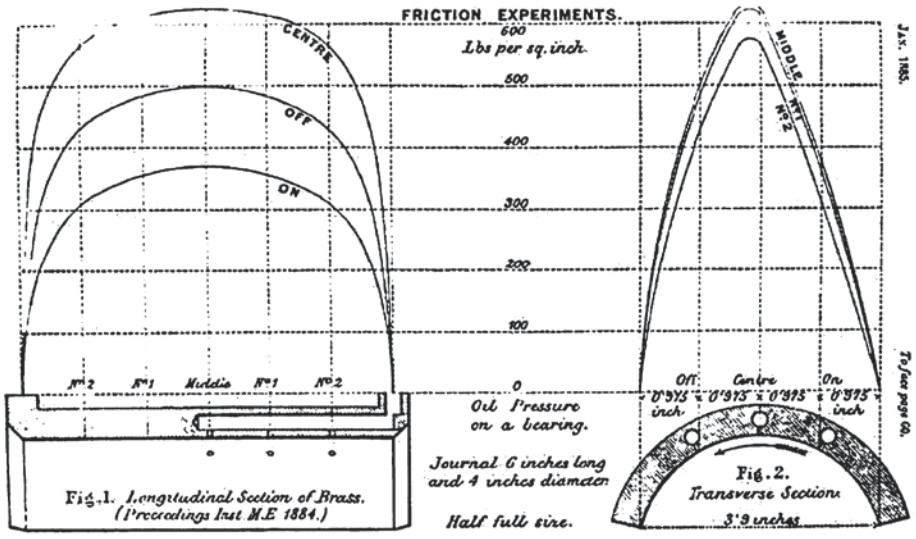
Past Is Prologue

Aaron Fagan, Senior Editor



Beauchamp Tower's 1885 measurements of oil pressure along and around a 4-inch railway journal, reaching nearly 600 psi at the center, well beyond the 200 psi his first gauge recorded in 1883. Osborne Reynolds compared his theory against these curves. **(Image: Proceedings of the Institution of Mechanical Engineers, 1885)**

Fluids have had a big year in the math pages. In August, *Quanta Magazine*'s "Theory of Fluids Enters the 21st Century" described physicists deriving the Navier-Stokes equations from symmetry and noting that the equations ignore a fluid's molecules. In September, OpenAI announced that AI agents had found a blowup in the 3D Navier-Stokes equations driven by an external force, a point where an idealized fluid's velocity runs to infinity. If it holds up, it would settle one of the Clay Mathematics Institute's $1 million Millennium Prize problems. Nobody expects either result to change how a gearbox is lubricated. Engineers have been getting by on approximations of their own for a long time.

In 1883, Beauchamp Tower, testing railway axle bearings for the Institution of Mechanical Engineers, ran a journal in a bath of oil and measured friction coefficients as low as one part in a thousand. Late in the work, he drilled a hole in the bearing for an oil feed, and when the shaft turned, oil welled up through it. He stopped the hole with a wooden plug, and the oil pushed the plug out. A pressure gauge read more than 200 pounds per square inch. The shaft was riding on a wedge of oil that its own rotation had dragged in and pressurized, which is why the friction was so low.

Osborne Reynolds explained Tower's results in 1886. He started from the Navier-Stokes equations and discarded the terms that become negligible when a film is far thinner than it is long, leaving an equation for the pressure in the oil. Even his rough solution matched Tower's measurements. The Reynolds equation is still the basis of bearing and gear lubrication design.

Gears gave the theory an honest test. In 1916, H.M. Martin applied Reynolds' equation to meshing teeth, treating the steel as rigid and the oil's viscosity as fixed. His films came out a few hundredths of a micron thick, far thinner than the roughness of the tooth surfaces. By his numbers, the teeth should have been grinding metal on metal, yet gearboxes ran for years. The answer came from A.M. Ertel and A.N. Grubin in Moscow in the 1940s and from Duncan Dowson and Gordon Higginson at Leeds in 1959. Under load, the teeth flatten elastically, and the oil between them, at 1 to 2 GPa, roughly 10 to 20 times the pressure at the bottom of the Mariana Trench, becomes so viscous it behaves almost like a soft solid. With both effects included, the film comes out at a few 10ths of a micron or more, enough to keep the teeth apart. The field is called elastohydrodynamic lubrication, and its film formulas are built into the standards used to rate gears for micropitting and wear.

The improved theory has a limit. The Navier-Stokes equations assume oil behaves like a simple liquid, one whose resistance is proportional to its shear rate. Oil at 1 GPa does not. It thins as it is sheared, and past a certain point, it stops resisting harder and slips. Friction in the mesh depends on that behavior. Tribologists have measured it on test rigs for decades and fitted models to the results, which is why any new lubricant still must be tested. Those models describe what the oil does better than they explain why.

The physicists in the August *Quanta* story are working on the general form of that question, using symmetry to work out how a fluid must behave once the simple equations stop fitting. So far, their methods apply only to fluids close to equilibrium, and nobody knows whether they will reach oil at 1 GPa. If they do, they could explain what gear engineers have been observing all along. Practice has run ahead of theory before. Steam engines ran for about a century before Sadi Carnot explained them in 1824, and Kepler described how the planets move about 70 years before Newton showed that gravity was the reason.

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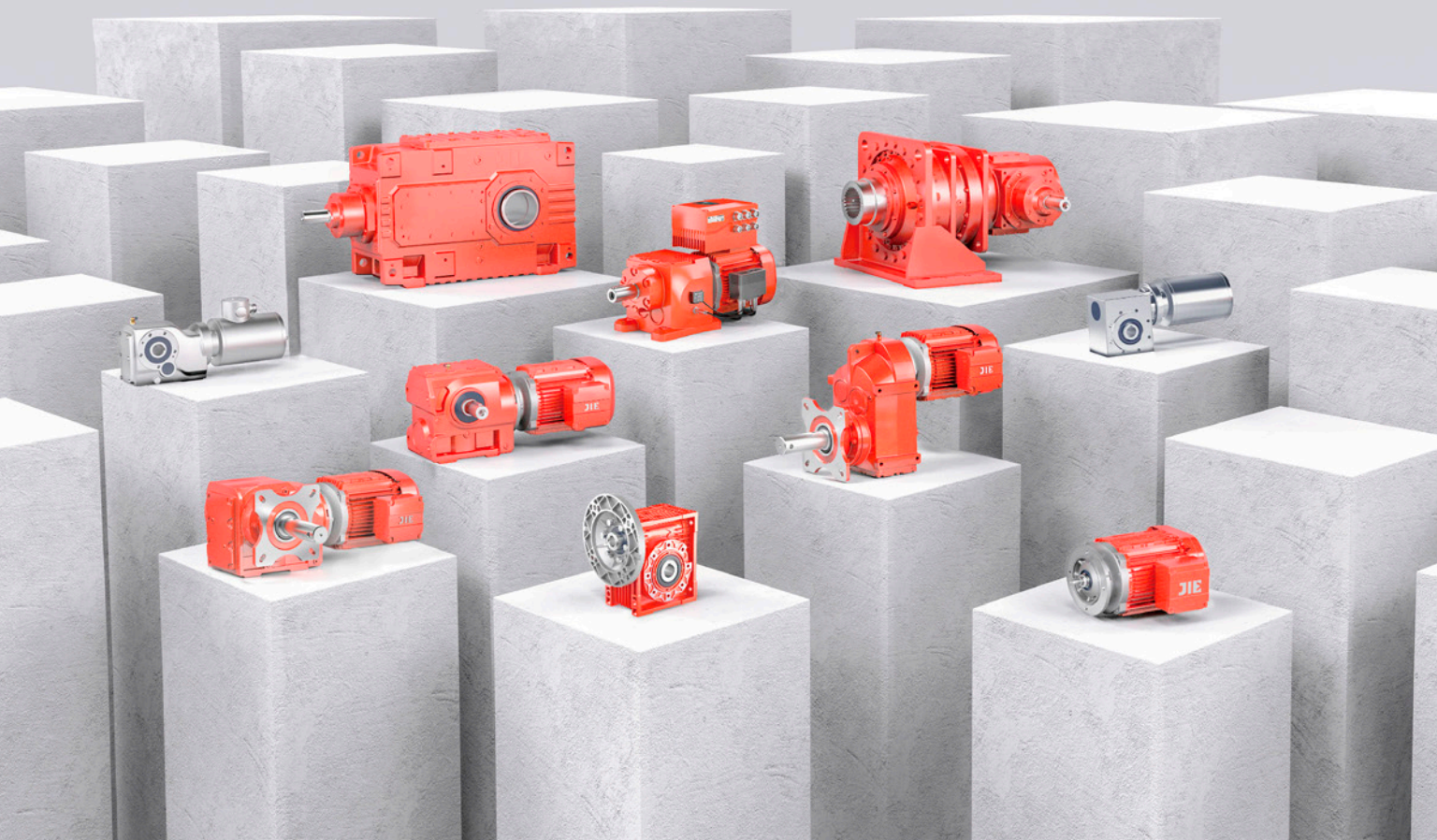

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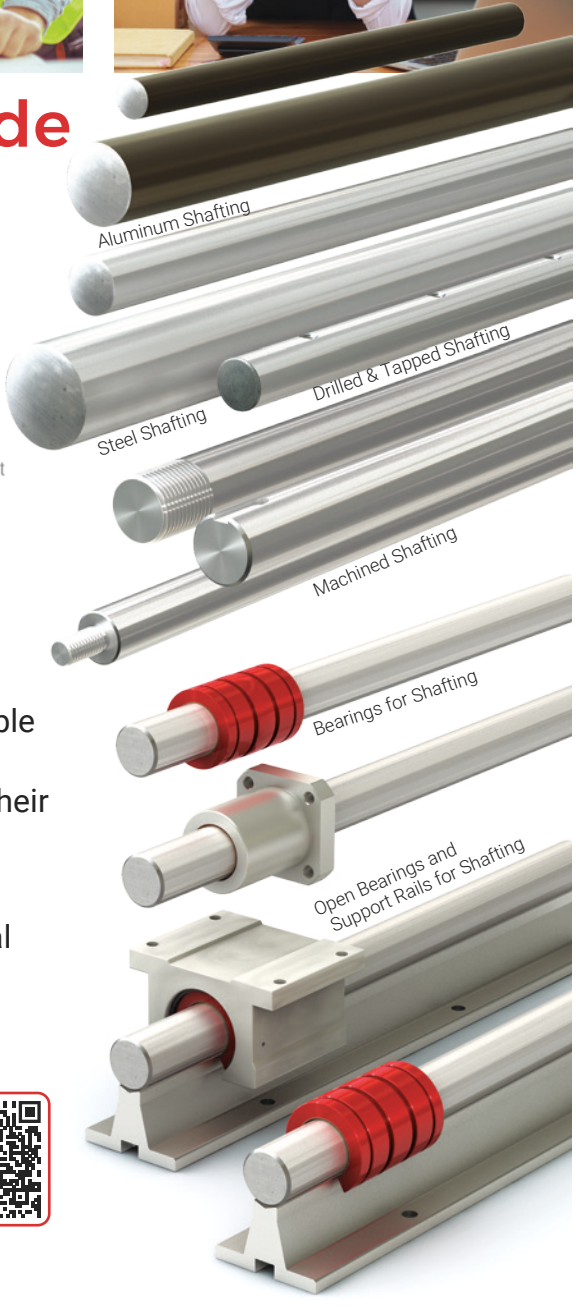

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